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Engineering News-Record

December 21, 1933

Boulder Dam Progress

THE SECOND construction stage on the Boulder Dam project is fast becoming history. Notable accomplishments have followed one another in rapid sequence. A year ago our issue of December 15 was composed of ten articles commemorating the completion of the first stage of the construction. Such a high tempo of activity had been maintained on that preliminary work, leading up to river diversion, that the project was a year ahead of schedule. Now, after another twelve months of even greater accomplishment, the work appears to be a full two years ahead of the originally scheduled date of completion. How such success has been achieved is told in the following:

A Year of Achievement, by Elwood Mead
Future Plans at Boulder Dam, by R. F. Walter
Mass Concrete and Heat Control, by B. W. Steele
Reviewing the Accomplishments of 1933
Mass Concreting at a Record Rate
Refrigeration of Mass Concrete
Welding Heavy Steel Penstock Pipe
Huge Side-Channel Spillways for Flood Control
Record-Size Cableway Spans Black Canyon
Intake Towers and Penstock Tunnels
Mystery of Inner Gorge Revealed by Excavation

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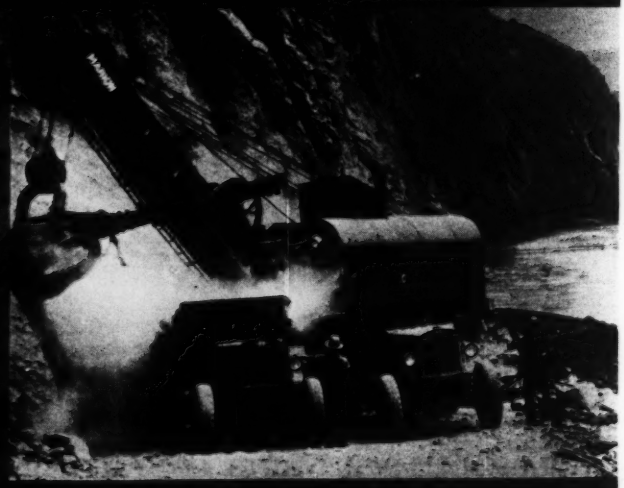

Shock loads . . . abrasive dust

SECOND STAGE AT BOULDER DAM

This issue chronicles the operations involved in stage 2 of the Boulder Dam construction. By chance it follows just a year after the special issue of Dec. 15, 1932, which was devoted to stage 1, the work leading up to river diversion. Progress then was one year ahead of schedule; due to remarkable speed of construction during 1933 it is now a full two years ahead. The procedures which have made this record possible are described in eleven articles in this issue.

Engineering News-Record

New York

December 21, 1933

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A Year of Achievement at Boulder Dam

By Dr. Elwood Mead
Commissioner, U. S. Bureau of Reclamation, Washington, D. C.

I VISITED Boulder Dam on November 15. An interval of one year had elapsed since my preceding visit. In that time the river had been turned from its course, the foundations of the dam excavated, the concrete mixing plant and works for the fabrication of penstock pipes had been erected and put in operation. It had been a year of remarkable achievement, marked by the installation of equipment of greater size and strength than ever before required or used. A number of construction records had been broken.

The construction of Boulder Dam and power plant goes on day by day with the same order and efficiency that has marked these operations from the beginning, but today construction is more varied and complicated. Six Companies, Inc., is not only building the dam, but is driving and lining penstock tunnels and preparing the foundations for the power house. The Babcock & Wilcox Co. is fabricating the great penstock pipes. The gates that regulate the flow of water to the turbines are being installed and in half-a-dozen great factories of the country, power equipment, of which the turbines and the generators are the largest ever made, is being constructed. This requires that different operations shall fit into each other to avoid confusion and delay. It places on the Bureau of Reclamation a greater burden than ever before in preparing for the contractors the details of plans. The tracings of these details turned out of the Denver office each month run into hundreds. The accompanying view is indicative of the operations that are plugging the gorge of the Colorado River for the first time.

Black Canyon as it appears at present. Nearly 1,000,000 yd. of concrete have been placed in Boulder Dam.

The area between Boulder City and the dam site, including the canyon walls on both sides of the river, is more striking than ever before. Thousands of tourists visiting the project each week are carrying back to their homes stories of the impressiveness of these colossal operations. A tourist bureau to pilot visitors and explain what it all means is being run as a private enterprise and is proving a profitable convenience.

The network of highways which traverse the deep gorges and precipitous cliffs between Boulder City and the dam is one of the spectacular features. Buses traveling over these roads carry 150 workmen at a load from Boulder City to the job. Scenic panoramas of the highway are supplemented by those of the bridges and suspended cableways that span the river from canyon wall to canyon wall. Some of these cableways are the largest ever made, and with powerful operating machinery are a vital factor in the employment of thousands of workers, who continue to make new records in speed of construction.

It now appears that water will begin to be stored in 1934

and power generated in 1935, nearly two years in advance of the original schedule.

When I first saw the site of Boulder City it was a hideous desert. Now attractive headquarters of the government and contractors, churches, stores, a motion-picture house, the largest in Nevada, and the new hotel, all set in an expanse of well-kept lawns and thousands of trees and shrubs, present a picture not only of comfort but of beauty, which has helped to develop in more than 5,000 residents a civic pride that is one of the influences which goes to build up the remarkable morale of this organization. To the original desire of the Bureau to do all that was possible to insure health and comfort to the workers, there has been added, through cooperation with those workers, an attractiveness and beauty that is causing many of the business men and workers to desire the town as a permanent home. They are hoping that the completion of the dam may be followed by the establishment of industries which, with the visitors attracted by the scenic beauties of the great lake that is to stretch up the canyon for 100 miles, will make Boulder City a permanent and substantial town.

On my recent visit I first visited the canyon at night. The 20-ton buckets carrying 8 cu.yd. of concrete at a trip were being loaded and handled more quickly and with more accuracy than even seen before. This smoothness of operation permits more than 6,000 cu.yd. of concrete to be placed in the dam each day. This speed has been made possible by the improvements in the details of the cooling system, under which the 2-in. pipes originally contemplated have been displaced by 1-in. tubes with very thin walls, by which the temperature of the concrete is being lowered to 54 deg. before the next layer is placed.

Benefits are nation-wide

An interesting point about all these construction operations is the wide distribution of the money spent for the project. A common error of thinking assumes that this money is expended in Arizona and Nevada alone, but at this time 40 per cent of the monthly payrolls are going to buy steel, pay for fabrication of gates, turbines and generators, all of which comes from east of the Mississippi River. One has to talk with those who operate these great industrial works to know what a contribution the construction of Boulder Dam is proving to be to our industrial recovery.

The personnel that planned this development and that is directing construction has shown itself equal to the task. In the Reclamation Bureau R. F. Walter, as chief engineer, John Savage, as chief designing engineer, and Walker Young as construction engineer have ably met the emergencies and the difficulties as they arose. Six Companies, Inc., is a great organization. Frank Crowe and Charles Shea have shown courage and resource of high order. The fabrication of the penstock pipes, 30 ft. in diameter, is a major engineering problem. I. Harter, vice-president of Babcock & Wilcox Co., who directs this, belongs to the Boulder Canyon group. On the whole, this construction is a research school in engineering. Boulder Dam and power plant not only mean great structures but a distinct advance in engineering science and methods.

Reviewing the Past Year at Boulder Dam

By J. I. Ballard
Pacific Coast Editor, Engineering News-Record

TWELVE MONTHS AGO the preliminary stage of construction on the Boulder Dam project had been completed, marked by the diversion of the river, and work was centered on building the permanent cofferdams, excavating the dam site proper and concreting the dam to an elevation above flood level. Today, this second and intermediate stage of the program is fast becoming history and the operations are settling down to the final stage—manufacturing and placing 3,400,000 cu. yd. of concrete in the dam. A year ago the work was described in terms of "excavation and trucks"; today the feature is "concrete and cableways." Then, it was a deafening roar of machines and explosives in the fierce drive to get the cofferdams finished and the site ready; today, the atmosphere is characterized by a quiet, orderly rhythm of concrete placing with the swing of giant cableways. A year ago, at the completion of the first major stage of the construction program up to the diversion of the river, the history of the project and a review of all operations were presented in a special number of *Engineering News-Record*, Dec. 15, 1932; the present issue brings this reporting to date. This second progress review outlines the work of the past year and describes in detail the concrete, its development and characteristics, and the methods of placing which will constitute one of the main features of the work for the following year. For the proper orientation of the material presented in the following pages and to provide a link between these two special issues it is proper to review briefly the accomplishments of the past twelve months.

When the river was diverted from its channel into the 50-ft. diameter tunnels on Nov. 13, 1932, it was the signal for the start of a phenomenal excavation and earth-moving operation. To insure an uninterrupted construction program in the canyon, it was essential to complete the two permanent cofferdams before the spring and summer flood season of 1933. It was equally important to prosecute the excavation of the dam site at the same time from the standpoint of economy in time and use of equipment. As a result, the two operations were combined, and week after week trains and trucks moved in and out of the canyon at an ever-increasing pace. During the month of December 440,000 cu. yd. of fill was placed in the upstream rolled-earthfill cofferdam, and the total excavation handled for the same month—fill going into the canyon and rock coming out—was 593,000 cu. yd. This work (*ENR*, June 15, 1933, p. 776) involved the use of about 80 trucks and seven trains and continued at high speed through the month of March.

The volume of excavation decreased as the work approached final clean-up late in the spring with the opening up of the narrow gorge in the center of the channel (page 735). Finally, foundation

One of the pleasing vistas in Boulder City, looking from the yard in front of the administration building toward the hospital of the Six Companies. Other sections of the town still retain much of the desert character, with no grass and the sand drifting over sidewalks and streets.

rock was exposed over the entire area and received geological approval. Along the line of the upstream face of the dam the cutoff trench was extended farther into rock, narrowing to a width of about 10 ft. and extending at its lowest point to El. 503, which is about 140 ft. below original low-water surface (El. 645) at the site. This depth for the lowest concrete fixes the total height of the dam as 729 ft. to the crest at El. 1,232. In June, 1933, concrete placing started in the dam. The concrete to form this 3,400,000-cu. yd. mass, its antecedents, the cement, the mix, forms, placing and the important cooling system are described in the following articles.

While this essential work was going forward, other features were kept in step to balance the accelerated construction program. The two side-channel spillways high on the sides of the canyon, with a total capacity of 400,000 sec.-ft., were practically completed and are described by the designer in the article on page 754. In preparation for the fabrication and installation of the steel penstock pipes, a large ultra-modern steel-fabricating plant, including provisions for X-raying welded joints, had been built near the site and was placed in operation, rolling and welding sections of penstock. The plant and the methods of fabrication are described on page 751. Also, the tunneling program to complete the smaller penstock and outlet tunnels has been completed, and lining is under way on these smaller bores (p. 757).

During the year the floodflow of the river did not exceed 80,000 sec.-ft., as compared to about 100,000 sec.-ft. for the preceding year, which is about average. Of course, floodflows up to 200,000 sec.-ft. are provided for by the permanent cofferdams, which were completed months before the 1933 flood season, but the low peak provided a construction advantage in allowing the turning of the river out of one or two of the tunnels by temporary dams, to permit work on final grouting and connection to the spillways to be continued.

With almost one-quarter of the concrete already placed in the dam, the project continues to move forward toward a completion date of Dec. 31, 1936. The dam itself, according to present schedule, will be completed in a nineteen-month period, ending about December, 1934.

Future Progress Recharted on Work Yet to Be Done

By R. F. Walter
Chief Engineer, U. S. Bureau of Reclamation, Denver, Colo.

ON DECEMBER 15, 1933, more than 800,000 cu.yd., or about a fourth of the total of about 3,400,000 cu.yd. of mass concrete in Boulder Dam, was in place. At the time of letting the construction contract in March, 1931, the tentative construction program called for placing the mass concrete during the period from December, 1934, to August, 1937. If present progress of placing continues, this feature of the work will be completed by May 1, 1935, or two years and three months in advance of the date originally contemplated.

One year ago construction had progressed so rapidly that it was then estimated that the river-diversion bulkhead gates could be closed and storage of water commenced on June 15, 1935, or one year ahead of the original program. Now it appears that there is an excellent prospect of performing this operation in the late summer of 1934.

In addition to placing the balance of the mass concrete in the dam, there remains to be completed the construction of the following major features: the intake towers, the plate-steel pipe in the pressure tunnels, the canyon-wall outlet works, the downstream tunnel plug outlet works, the power house and the removal of the downstream cofferdam and rock barrier.

Of the appurtenant works, probably no feature attracts as much attention as the four intake towers of reinforced-concrete constructiton. These towers, tapering from an overall diameter of 82 ft. at their bases to about 64 ft. at their tops, will rest on the canyon walls upstream from the dam, two in Arizona and the other two in Nevada. They are identical in design and will rise from a foundation elevation 388 ft. higher than the lowest point of foundation excavation for the dam. The total height to the top of the gate-operating house will be 380 ft. Each tower will house two 32-ft. diameter cylinder gates, one at the base and the other 150 ft. higher, by which storage water will be released to the outlet and power penstock tunnels.

Geological investigations give no indication of recent seismic disturbances in the vicinity of the dam, but on account of the great height and relative slenderness of these towers it was considered wise to design them to take earthquake shock. Thus, while concrete in each tower will amount to only 21,000 cu.yd., 6,500 tons of steel bars will be used to provide heavy reinforcement, amounting to slightly over 150 lb. of steel per cubic yard of concrete.

Single-span steel girder bridges with framework incased in concrete will connect each downstream tower to the top

Excavation of the deep central notch in the floor of the canyon was well advanced by May 1, 1933 (left), and concrete placing started in this area about the middle of June (right).

A network of cableways swings high over the gorge. This one and its mate, both of the traveling type, serve the two spillways and the upstream portion of the dam.

of the dam, and to the upstream tower on the same side of the canyon. The average span length of each of these four bridges will be 107 ft.

Excavation for the towers has been completed and construction of the two towers nearest the dam is starting, with the expectation that they will be completed by next June. Present construction plans anticipate completion of the two upstream towers by January, 1935, and the construction of the connecting bridges during the spring of that year.

Excellent progress has been made during 1933 by the Babcock & Wilcox Co. on its contract for furnishing and installing the plate-steel outlet and power penstock pipe. The steel plates are shipped to the modern fabricating plant erected by the contractor near the dam site, where they are rolled and welded into circular sections convenient for short-haul railroad and truck transportation to the top of the canyon downstream from the dam on the Nevada side. The fabricated sections are then moved by a permanent 150-ton cableway, provided by the government, to the mouths of construction adits in the canyon walls, whence they are transported to their final position in the concrete-lined tunnels and joined to adjacent sections.

The total weight of installed plate steel involved in the contract is 44,820 tons. The largest fabricated sections will be 30-ft. inside diameter and 24 ft. long, with a maximum plate thickness of $2\frac{1}{4}$ in. Such a section will tax the capacity of the permanent cableway.

It is expected that all pipe in the tunnels leading from the downstream intake towers will be installed and ready for operation by late fall of 1934, and that the balance of the pipe will be installed during 1935 and 1936.

The canyon-wall outlet works, located on each side of the canyon at the ends of the upper penstock tunnels, will regulate the flow of all stored water released through the downstream towers that is not used for the generation of power. A valve house will be constructed on each side inclosing six 84-in. internal differential needle valves and an emergency gate for each. These valve houses, perched on narrow shelves excavated high upon the canyon walls, will be about 65 ft. high, 35 ft. wide and almost 200 ft. long, the last dimension being parallel to the canyon. Excavation for these houses has been completed recently, and their erection should be finished before next summer.

The downstream tunnel plug outlet works, located in each 50-ft. inner diversion tunnel several hundred feet upstream from the outlet end, will regulate the flow of all stored water released through the upstream towers, which is not used for the generation of power. The interior chambers that house these outlet works will have a maximum width of about 115 ft. and a height at the location of the gate-operating gallery of about 65 ft. The chambers require the widening of the diversion tunnels for a length of almost 200 ft. Each chamber will house six 72-in. internal differential needle valves and an emergency gate for each.

A large part of the excavation for the tunnel plug outlet works has been completed, but present plans call for the major construction and the completion of these works during the first six months of 1935.

The power house, located at the downstream toe of the dam, will consist of two wings, one on each side of the river, which will be connected at their upstream ends by a structure accommodating operation, shop and storage rooms. The river face of each wing will have an over-all length of about 575 ft., a depth from this face to the excavated canyon wall of 76 ft. and a height from the generator floor to the top of the roof of 85 ft.

Present plans provide for placing eight 82,500-kva. units in the Nevada wing, and seven 82,500-kva. units and two 40,000-kva. units in the Arizona wing. All power-plant machinery is to be installed by the government as needed. The greater part of the foundation excavation for the power house has been completed. It is planned to complete the power-house substructure by June, 1934, and the superstructure prior to the following September.

After completion of the power house the downstream cofferdam and rock barrier must be removed to clear the tailrace for the generation of power. This will require the excavation and disposal of over 400,000 cu.yd. of earth and rockfill materials, which it is planned to accomplish during the winter of 1934-'35. It is expected that the first power units will be placed in operation in September, 1935.

A number of smaller features, and of somewhat lesser importance than those mentioned, will be in progress of construction during the next three years. It is more than likely, judging from the past rapid progress made, that all features of the work will be completed by the early spring of 1937, or at least a year in advance of the date originally contemplated.

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Mass Concrete for Boulder Dam— Its Development and Characteristics

Size and construction speed dictate new provisions to control heat and shrinkage cracks—Properties of the aggregate and mix and advantages of the special low-heat cement—Problems of placing and cooling the concrete

By Byram W. Steele
Designing Engineer on Dams, Bureau of Reclamation, Denver, Colo.

CONCRETE PROBLEMS of a magnitude never before encountered in dam construction provide one of the outstanding features of the Boulder Dam project. They result directly from the record-breaking height of the structure and the relation of this dimension to the mass of concrete, for if the dam had been twice as long as any previous dam, rather than twice as high, it would not have attracted such widespread attention or involved the present concrete problems. However, it was the volume of concrete which resulted in expenditures that, in turn, made feasible the research commensurate with the magnitude of the problems.

The preliminary results of these studies, which can now be reviewed in part for the first time, should form the basis for opening a new era in the field of large concrete-dam construction. It is the intent of this article to present a review of developments in mass-concrete work that have resulted from the years of experience of the Bureau of Reclamation in the design and construction of dams, with special reference to the unusual features of the concrete used in constructing Boulder Dam.

Past Experience — The Bureau of Reclamation has been placing concrete in large and small masses since its establishment in 1902. The variety of operating conditions embodied in its experience resulted in various conclusions, including the judgment that it was not economically practicable to introduce larger rock into mass concrete than could be run through the mixer. It was also apparent that the design of mixers to handle cobble-rock concrete warranted further study to the end that the batch would be a uniform mass when dumped. The attainment of uniformity in a mass-concrete mix containing cobbles is much more difficult than in other classes of concrete.

This experience indicated the desirability of a combined field and laboratory study of the maximum size of aggregate permissible in mass concrete and the minimum cement requirement for satisfactory results, together with many other specialized problems. Not until the construction of Boulder Dam was authorized, however, did the expenditure of sufficient funds to carry on such experiments seem warranted.

Recent developments

In recent years it has been noted that the combination of construction speed, rapid-hardening cement with attendant greater evolution of heat, and higher dams has resulted in increasing the volume change in mass concrete and consequently has accentuated the number and width of contraction cracks.

Fig. 1—Early progress on a 3,400,000-cu.yd. mass of concrete, 650 ft. thick from up- to downstream face, that presented a great many problems of unprecedented magnitude. Note the columnar construction, the central 8-ft. slot for the cooler-pipe headers and concrete placing under way on one of the blocks in the foreground.

It has always been customary in dam construction to form radial or transverse contraction joints, but not until these modern factors became cumulative did the necessity for longitudinal contraction joints become evident. Cracking is objectionable in any structure, of course, but it is believed that cracks in a hydraulic structure, such as a dam, should be especially avoided, since they may directly or indirectly affect the stability, permeability, appearance and durability of the structure.

The primary cause of cracking is volume change resulting from temperature variations. To control this volume change so as to obtain, by means of contraction joints (designed cracks) and pressure-grouting, a monolithic dam, necessitated research along many lines and resulted in the inauguration by the bureau of an unprecedented program of mass-concrete research. This study has been in progress for the past 2½ years and is now approaching completion.

Stress distribution

In the construction of any large dam the engineering problems may be placed in two groups: (1) a design to secure a satisfactory distribution of stress; and (2) a construction plan that will result in essentially the same distribution of stress in the finished structure as contemplated in the design. To fulfill the latter, the various parts of the structure must be capable of transmitting compression and shear to all adjacent parts, which in turn requires proper shaping of the contact surfaces between adjacent sections with regard to the direction and magnitude of the stresses to be transmitted.

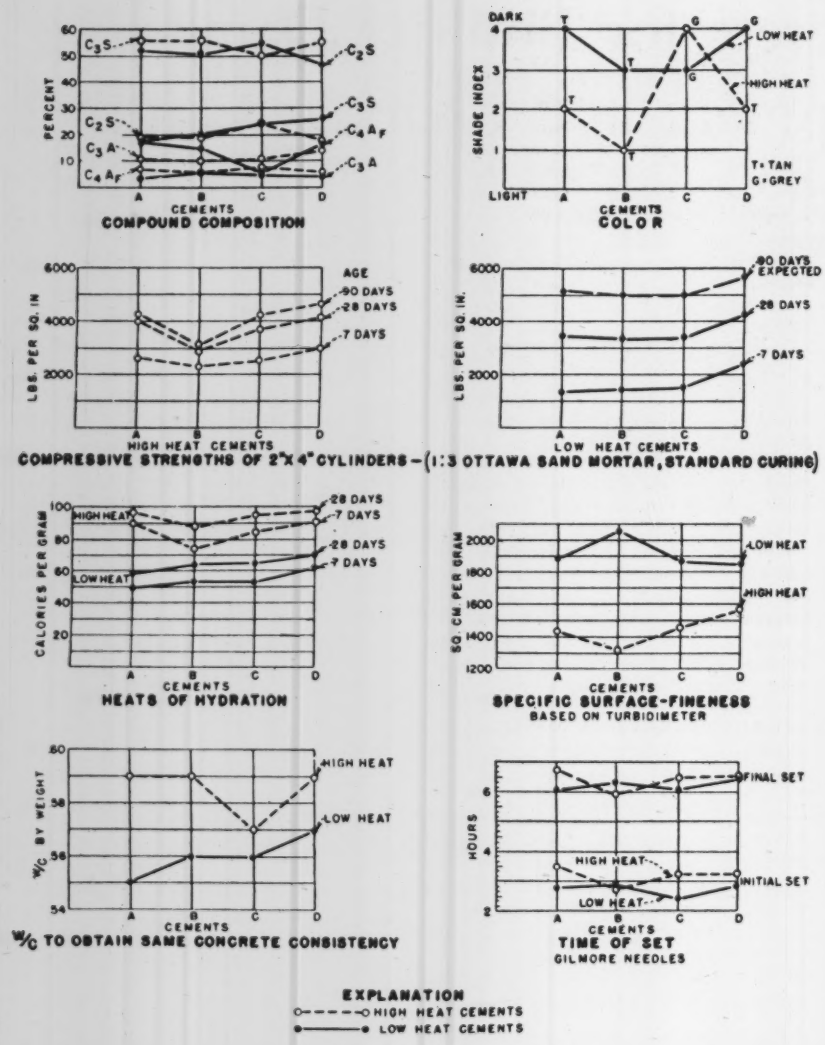


Fig. 2—Characteristics of the low-heat cements compared to the standard cement from the same four mills (A, B, C and D) based on laboratory studies.

All of the above assumptions imply a structure which is in effect monolithic. If it is not monolithic and volumetric changes take place within the structure, the desired stress distribution does not obtain.

The method of providing for volume change within the mass is treated later in the discussions of refrigeration and grouting. If this volume change were not provided for, a sequence of stress distribution would begin at the time of completion, with initial expansion to maximum volume as a result of the chemical heat generated by the hydrating cement, placing all parts of the structure in contact. The resulting structural unit and the stress distribution would be only temporary, however, for, as the heat within the mass was dissipated and the exposed surfaces cooled and contracted, parts of the dam would be called upon to assume additional load. This process of cooling and contraction from the exterior might be conceived to continue until a condition is reached where the entire load on the structure is carried by a central core, still intact, with a unit stress greatly in excess of the allowable, possibly impairing the safety of the structure.

To correct this condition would require successive grouting of joint openings and shrinkage cracks over a long period of time, as is being done in the case of one of the high dams in this country. This type of treatment is not well adapted to a structure of the magnitude of Boulder Dam and would place responsibility for the safety of the structure on a future generation of operators who might not appreciate the gravity of the situation. The adopted plan of cooling and grouting as construction proceeds, however, will result in a monolithic structure, the safety of which will not be impaired by volumetric change.

Specifications

In the concrete specifications for Boulder Dam, special provisions were included to insure a mass-concrete structure superior to any heretofore constructed. In brief, the specifications represent an attempt to secure those qualities which make for the greatest durability of mass concrete at the lowest practicable cost. As evidence of the generally favorable reception accorded these specifications, it has been noted that several specifications for dams published since have provided for similar methods and materials.

Proportioning by weight, which had become generally accepted practice, was incorporated in the specifications and was amplified by providing that "The equipment shall include an accurate automatic recorder, capable of being locked, for visibly and graphically recording the time of weighing and the actual amount of each separate concrete ingredient weighed out." Further, the desire for greater uniformity in concrete consistency from batch to batch led to the provision which required the contractor "to equip each mixer with an efficient recording consistency gage and timer" for indicating and recording the consistency of the mix during its sojourn in the mixer.

Maximum slumps were specified for the various classes of concrete, with the provision that "Only sufficient water shall be used to secure a plastic concrete of suitable workability which, without segregation, will flow or can be worked properly into place with thorough spading or working," and with the further provision that "The government reserves the right to require a lower water-cement ratio in any and all mixes than required to produce these slumps whenever, in the opinion of the contracting officer, such lower water-cement ratios are practicable and will produce concrete of better quality."

The curing of mass concrete in the dam was adequately provided for in the specifications by the provision that "All horizontal construction joints in the dam . . . shall be kept continuously moist, regardless of time, until they are covered with concrete," and that "The upstream and downstream faces of the dam and the surfaces of all contraction joints in the dam shall be kept continuously moist for at least two weeks after the concrete is placed."

Special cement

Desire for the utmost in durability was the primary motive which dictated the features of design and construction. The selection of a special cement was only one of the many developments in connection with the manufacture of mass concrete.

Cement having qualities different from that usually purchased under federal specifications SS-C-191 was first considered to assist in control of maximum temperatures in the concrete and thus decrease the total amount of heat to be extracted. Since it was necessary to control the chemical composition of the cement to obtain lower heat-generating qualities, it was decided to investigate

at the same time the possibility of obtaining other desirable qualities such as: (1) increased workability by closer control of the fineness; and (2) greater durability by modifying the chemical constituents. Cement specifications were reviewed in *Engineering News Record*, Nov. 10, 1932, p. 558. The cement is at present being purchased from four mills in southern California and blended at the dam site.

The reduction in water-cement ratio that resulted when the special cement was substituted for standard cement in August was from 0.642 to 0.597. Fig. 2 indicates the principal properties of four brands of low-heat cement and regular commercial cement from the same mills. The data applying to low-heat cement are representative of about 200,000 bbl. used during September, 1933. In general, the characteristics of the finely ground special low-heat cements (high in dicalcium silicate and low in tricalcium silicate and tricalcium aluminate) as compared with the higher-heat commercial cements are:

(*a*) Heat generation about one-third less.

(*b*) Marked improvement in workability of concrete with lower water-cement ratio, due principally to higher fineness.

(*c*) Greater uniformity of concrete as a result of blending and controlling composition.

(*d*) Less rapid strength development but probably greater ultimate strength in mass concrete.

Results of recent research also indicate that greater durability may be expected with the special cement now being used at Boulder Dam as a result of the decreased tricalcium aluminate content. In this connection it is believed that control of this compound, as adopted for the limiting of generation of heat, is worthy of serious consideration for all cements because of the apparent effect on durability.

Standard cements from different plants, and even from the same plant over a period of time vary considerably in physical and chemical properties due to the variability of raw materials and manufacturing control. As a result of the improvement brought about by blending, it is a certainty that if the project were to be started over again, all cement would be blended to eliminate the trouble experienced from non-uniformity of cement of various brands.

TABLE I—GRADING OF ARIZONA GRAVEL USED IN BOULDER DAM CONCRETE

Sieve Size	Sand		Gravel		Combined	
	Per Cent Retained	Cumulative Per Cent	Per Cent Retained	Cumulative Per Cent	Per Cent Retained	Cumulative Per Cent
9 in.	.....	.....	0	0	0	0
6 in.	.....	.....	9.41	9.41	6.98	6.98
3 in.	.....	.....	21.61	31.02	16.04	23.02
1½ in.	.....	.....	23.48	54.50	17.41	40.43
¾ in.	.....	.....	20.63	75.13	15.31	55.74
¾ in.	.....	.....	14.63	89.76	10.85	66.59
No. 4	.....	.....	10.24	100.00	7.60	74.19
No. 8	17.01	17.01	.....	.....	4.39	78.58
No. 14	11.63	28.64	.....	.....	3.00	81.58
No. 28	15.03	43.67	.....	.....	3.88	85.46
No. 48	41.54	85.21	.....	.....	10.72	96.18
No. 100	12.34	97.56	.....	.....	3.19	99.37
Pan	2.44	100.00	.....	.....	0.63	100.00
Total	100.00	F.M. = 2.72	100.00	F.M. = 8.60	100.00	F.M. = 7.08

TABLE II—PROPORTIONS OF THE MIX AND CHARACTERISTICS OF THE BOULDER DAM CONCRETE

	Size, (In.)	Proportions	Weight Dry-Rodded, Cu. Ft.	Spec. Grav.	Voids, Per Cent
Cement	.....	1.00	.....	....	..
Sand	.....	2.45	109.6	2.64	33
Fine Gravel	¼-¾	1.75	.....	....	..
Inter. Gravel	¾-1½	1.46	.....	....	..
Coarse Gravel	1½-3	1.66	.....	....	..
Cobbles	3-9	2.18	.....	....	..
All Gravels	.....	....	121.0	2.69	28
All Aggregates	.....	....	137.6	2.67	17
Water	.....	.54	.....	....	..

One part cement to 9.50 parts total aggregate.

Mass Concrete Characteristics:

Weight 156 lb./cu. ft.
W/C 0.54 by weight
Paste content 19.5%
Poisson's ratio 0.18
Slump 3½ in. at forms
Cement yield 1.01 bbl./cu. yd.
Modulus of elasticity 5,200,000
Strength (28 days) in 36x72-in. cylinders 3,100 lb./sq. in.

TABLE III—COMPRESSIVE STRENGTH OF BOULDER DAM MASS CONCRETE
(Pounds per Square Inch)

Test Age in Days	Full-Mass Mix, 9-in. Max. Size				Wet-Screened to 1½-in. Max. Size				
	18x36-In. to 36x72-In. Cyl.				36x72-In. Cyl.	6x12-In. Cyl.			
	Standard Cured		Mass Cured		Std. Cured	Std. Cured		Mass Cured	
	High-Heat cement	Low-Heat cement	High-Heat cement	Low-Heat cement	High-Heat cement	High-Heat cement	Low-Heat cement	High-Heat cement	Low-Heat cement
7	....	....	....	....	2,260	2,990	1,440	3,680	2,240
28	3,100	2,670	3,640	3,120	3,370	4,040	3,210	5,010	4,090
90	3,680	....	....	....	3,920	5,050	4,360	5,180	4,350
365	4,250	....	....	....	....	6,070	....	....	....

The mix

Mass concrete for Boulder Dam contains 1 bbl. of cement per cubic yard. The selection of this minimum cement content is the result of past experience, laboratory studies, design stipulations in regard to strength and a careful digest of available data on durability and permeability.

The Arizona gravel pit, the source of aggregate supply, is a typical water-borne deposit of well-rounded particles of excellent quality. The sand is largely quartz, while the gravel is made up principally of limestone, intermixed with granite, basalt and quartzite. The material is unusually clean and contains no organic impurities.

The average grading or yield of the deposit was determined from test pits. Grading was changed only slightly in the final mix design resulting from large cylinder tests in the Denver laboratories of the bureau. The only changes from the natural grading were: (1) slight reduction of the No. 48 and smaller sizes; and (2) crushing of the material retained on a 9-in screen. Limiting the maximum size to 9 in. was desirable from the standpoint of mixing and placing operations. Grading is shown in Table I.

Comparison of Table I and the characteristics of the proportions of the concrete mix shown in Table II indicates that Boulder Dam is essentially a transposition of the Arizona gravel deposit with the voids filled by a high-quality cement paste, since the paste content in the concrete is only 2 per cent greater than the void space in the dry rodded aggregates.

Properties of the concrete

Compressive strength of the concrete (Denver tests) is shown in Table III. In this table the term "standard curing" refers to storage in fog rooms maintained at 70 deg. F. (± 2 deg.), and "mass curing" indicates curing adiabatically in sealed containers on a rising temperature cycle for 28 days and at 70 deg. F. thereafter.

Extensive tests show that identical strengths for the full-mass mix (9-in. maximum aggregate) are obtained in 18x36-in., 24x48-in. and 36x72-in. cylinders. This fact greatly simplifies the testing of mass concrete, since an 18x36-in. specimen requires only one-eighth as much material as a 36x72-in. test cylinder.

Young's modulus for the full-mass mix in large cylinders varies from 5,200,000 to 6,500,000, according to curing, type of cement and age at test; the average value is about 5,700,000. The 1½-in. maximum wet-screened concrete in 6x12-in. cylinders gave values from 4,900,000 at seven days to 6,450,000 at one year. Poisson's ratio varies from 0.18 to 0.23.

TABLE IV—COMPARISON OF DENVER LABORATORY AND FIELD TESTS FOR CONCRETE

Test	Field	Denver Lab.
High-Heat Cement		
Net W/C by weight	0.56	0.53
Slump, in.	4¼	3¼
Actual 28-day strength	3760	4040
Adjusted 28-day strength	4250	4040
Low-Heat Cement		
Net W/C by weight	0.53	0.55
Slump, in.	3¼	3¼
Actual 28-day strength	3210	3210
Adjusted 28-day strength	3310	3210

The relation between full-mix strengths in large cylinders and the 1½-in. maximum wet-screened concrete in 6x12-in. cylinders (usual field-test specimen) is indicated in Table III. Apparently this relation for the Boulder Dam mix varies only with strength, while type of cement, method of curing and test age have no appreciable effect.

Unusually close correlation has been obtained between the field and laboratory. Various mixes have been tried in the field, and at present the field mix and gradation are almost identical to those established by the large cylinder tests in Denver and the test-pit explorations.

It is gratifying that this gradation has been proved by actual gravel-plant operations and that practically the only waste material is a small proportion of the finer sizes of sand which are removed by washing in the sand classifier.

The Denver laboratory and field values for water cement ratio, slump and compressive strength of 1½-in. maximum wet-screened concrete in 6x12-in. cylinders at 28 days are given for comparison in Table IV. High-heat (ordinary) cement was used in the lowest sections of the dam as a result of the advance in the contractor's placing schedule. The field values given for high-heat cement are averages for the period from June, when the dam was started, to August, when the use of low-heat cement was initiated. The values given for low-heat cement are averages for the month of September.

Field slumps are determined at the mixers and correspond to about 3 in. at the forms, the loss results from the appreciable length of time between mixing and deposition under conditions of extremely high temperature and low humidity. Reducing the field slump to 3¼in. would lower the water-cement ratio to 0.53, the same as the laboratory value.

Field strengths must be increased by 8 per cent to be directly comparable with the laboratory results, due to the fact that the uniform method of load application as used in the Denver tests yields higher values than standard loading (0.05-in. head travel at idling speed) employed in the field. The adjusted values (Table IV) for field strengths are reduced to the same water-cement ratio and method of testing basis as the laboratory results, for the purpose of direct comparison. The agreement, within 5 per cent for the high-heat cement and 3 per cent for the low-heat cement, is most remarkable considering the many variable factors involved, which singly or collectively might account for the difference.

The field strength of 3,210 lb. per sq. in., when increased by 8 per cent for uniform loading conditions, becomes 3,470, which, from the test results giving the relation between wet-screened and full-mass concrete, corresponds to a strength of 2,780 lb. for mass concrete in large cylinders at 28 days. It is to be noted that this value is somewhat higher than the 2,500-lb. strength required by the specifications.

The field and laboratory experience in connection with mix design and specifications indicates rather conclusively that the mix design can be more advantageously developed in the laboratory than in the field, provided the laboratory is suitably equipped, sufficient preliminary data regarding field conditions are obtained and representative samples of aggregates are available. The problem is essentially one of engineering design, and the solution is a function of the designing rather than the construction organization.

Placement

From the standpoint of both structural results and contractor's cost, the various phases of placing mass concrete are of vital importance. In Boulder Dam every effort has been extended to secure a high degree of uniformity of placement from batch to batch. The requirement for bottom-dump buckets was ar attempt to secure placement without segregation and with a minimum variation in the water content.

If it were economically practicable to deposit mass concrete in units of 1 or possibly 2 yd., so that no movement would be required except to provide consolidation and intimate contact with previous adjacent batches, there is little doubt but that 1- to 1½-in. slump concrete would be desirable. But when concrete is placed by cableway in 8-yd. buckets under remote control, it is virtually impossible to deposit the concrete exactly as desired. Consequently the concrete must be spread out and transported horizontally to some extent, necessitating flow within the mass and resulting in more or less segregation.

Gravity is the principal active force in the production of dense concrete. Spading, working, tamping and vibrating serve mainly to assist gravity in securing a minimum volume by a better arrangement of the component particles of the mass and by the expulsion of entrained air. Extensive tests in the Denver laboratories led to the conclusion that compaction by internal vibration as compared with other methods results in more uniform distribution of aggregate particles, improved quality and texture of the matrix, greater density and greater ease in placing harsh or dry mixtures. Conditions at Boulder Dam during the past summer months

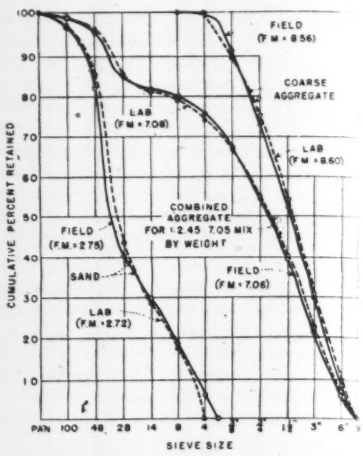


Fig. 3—Gradation of the mass mix showing the close relation of values obtained in the Denver laboratory and the field.

necessitated placing of the concrete on a slope in order to keep the working surface alive until another layer could be placed. The attainment of maximum density and uniformity is thus complicated, as there is a tendency toward the formation of porous areas along the slope between adjacent batches. This tendency is due to the fact that the surface concrete on the slope is unconfined and for this reason cannot be properly consolidated.

The specifications provided that, "In general, a wetter consistency than that corresponding to a slump of 3 in. at point of placement . . . will not be permitted for the main portions of the structure." Slumps from 1 in. up have been tried under actual operating conditions of placement in 8-yd. batches, and the conclusion has been reached that, all things considered, a slump of 2½ to 3 in. yields the most satisfactory results, eliminating the necessity for the use of vibrators. Concrete of 1- to 1½-in. slump is entirely practicable and will yield a superior concrete if properly placed and consolidated, but it cannot be properly placed in 8-yd. units with the mix proportions and placing equipment being used and under the climatic conditions at Boulder Dam. Even if it could, the net result would amount only to about 10 per cent increase in strength and corresponding improvement in related properties.

When the gain in strength, durability and impermeability of a drier mix are weighed against the increased harshness, cost of placement and tendency to nonuniformity in compaction due to decreased plasticity, the disadvantages will be found to outweigh the advantages, not because the ideal is impossible of attainment but because it is not practicable under the operating conditions prevailing on this project. It is far more important to have uniformity throughout the entire mass than to have slightly stronger concrete of questionable uniformity.

The foregoing is not a condemnation

of large units for placing mass concrete or of a 1- to 1½-in. slump concrete, but it is an attempt to point out that a happy medium based on a recognition of job conditions is often the only logical solution.

In the placing of mass concrete, the bonding of new concrete to old is a factor of considerable importance if watertightness is to be attained. Laitance or porous concrete along a horizontal joint provides a channel for seepage which may lead to objectionable consequences. Various methods for cleaning up the horizontal construction joints preparatory to a succeeding lift have been investigated by the bureau. As a result of past experience and recent experiments, it has been tentatively concluded that where concrete of proper consistency is obtained the clean-up shall consist of washing with air and water combined under high pressure as soon as the concrete has taken its initial set. However, if sloppy concrete has been used and laitance or inert material are present on the surface of the lift, or if the concrete has become hard, the film of inert or weak material shall be removed by chipping and wire-brushing. The potential watertightness of concrete of the regular Boulder Dam mix, under hydrostatic conditions applicable to the dam, has been amply demonstrated by permeability tests.

Contraction joint layout

The dam is divided into columns or blocks by radial and circumferential contraction joints. These blocks, for structural reasons, vary in size from 25x30 ft. at the downstream face at the base of the dam to 50x60 ft. at the upstream face. Concrete is required to be placed in 5-ft. lifts as the most satisfactory height for placing and cooling the mass under existing conditions.

The radial and circumferential surfaces of the contraction joints are interlocked by means of keys (see following article) formed to provide maximum cross-sectional area for resistance to shear after grouting. Metal grout stops are placed across radial contraction joints at both the upstream and downstream face of the dam and across the circumferential joints at each junction with a radial joint. In the vertical direction the stops are placed at 50-ft. intervals.

Concrete cooling

The stress distribution assumed in the design of the dam contemplates a monolithic structure devoid of cracks, as already discussed. This condition cannot be obtained until the internal temperature of the concrete at all points in the dam is reduced to a value varying from the mean annual air temperature at the downstream face to reservoir temperature at the upstream face. A study of these conditions indicates that there will be a theoretical temperature gradient through the dam, varying from 40 deg. F. at the upstream face, below the base of the intake towers (El. 900), to 72 deg. F. at the downstream surface of the dam above tailwater. The actual temperature of a narrow slab of concrete on the downstream face of the dam above tailwater and on the upstream face of the dam above El. 900 will fluctuate due to seasonal variation in temperature. Thus, it is evident that the internal temperature of the mass will not be the same at all points. The cooling system is being operated to produce as nearly as practicable the final temperature to obtain in the mass.

The cooling and shrinking of the concrete is accomplished by circulating water through 1-in. O.D. 14-gage tubing buried in the concrete. There are two stages in the process: (1) unrefrigerated river water is circulated as soon as concreting operations permit; this is followed by (2) refrigerated water at a temperature of 40 deg. F. The supply and return headers for the cooling system are located in a vertical radial slot 8 ft. wide in the center of the dam. Mains from the refrigeration plant connect with 6-in. headers and supply the 1-in. cooling-pipe system. The cooling pipes are spaced at 5-ft. intervals vertically and 5 ft. 9-in. intervals horizontally, and run in circumferential loops. The length of a cooling loop from header to abutment and return varies with the position in the dam, from about 600 ft. in the lower levels to about 1,160 ft near the crest. [Details of the refrigeration plant and the cooling system ar e described in a separate article, p. 748.—EDITOR.]

As already stated, the concrete placed in the inner gorge at the base of Boulder Dam contained standard portland cement. An average maximum temperature of 127 deg. F. was recorded in this part of the mass concrete. It is anticipated that the average maximum temperature of the mass concrete in which low-heat cement is used will not exceed 115 deg. F. next summer. An average maximum temperature of 80 deg. F. is predicted for this winter. These predicted values are based on an average temperature of 30 deg. F. The maximum temperature at any point, of course, is an extremely variable quantity depending on location, distance from horizontal and vertical surfaces, time these surfaces are exposed, weather conditions, wind velocities in the canyon, time artificial cooling is started and other factors.

Resistance thermometers in sufficient number for determining the control of the cooling operations are being installed in the mass concrete as the work progresses. In addition to the temperature data furnished by these resistance thermometers distributed throughout the mass, check tests on results of the cooling operations are being made periodically by disconnecting loops at various places, allowing 48 hours for the temperature in the concrete surrounding the loop to equalize, and then inserting thermometers distributed throughout the loop to equalize, and then inserting resistance thermometers 25 to 30 ft. into either end of the loop from the surface of the cooling slot for temperature readings.

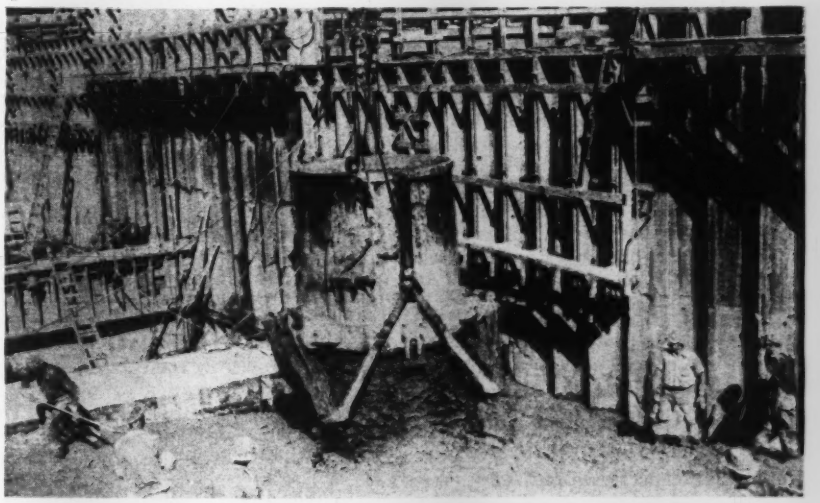


Fig. 4—Little evidence of segregation is indicated in the action of depositing 8 yd. of concrete by bottom-dump bucket. Note the keyways on the radial joint at the right and the form construction.

Deformations within the mass resulting from hydration of the cement and from construction operations are indicated by a system of strain meters buried in the concrete. These strain meters also serve as resistance thermometers and will later serve to indicate deformation in the mass caused by water load as the reservoir fills.

The widths of contraction-joint openings are being checked at various locations by means of Carlson joint meters that operate on the same principle as the Carlson strain meter (*ENR*, Oct. 15, 1931, p. 615), except that the struc-

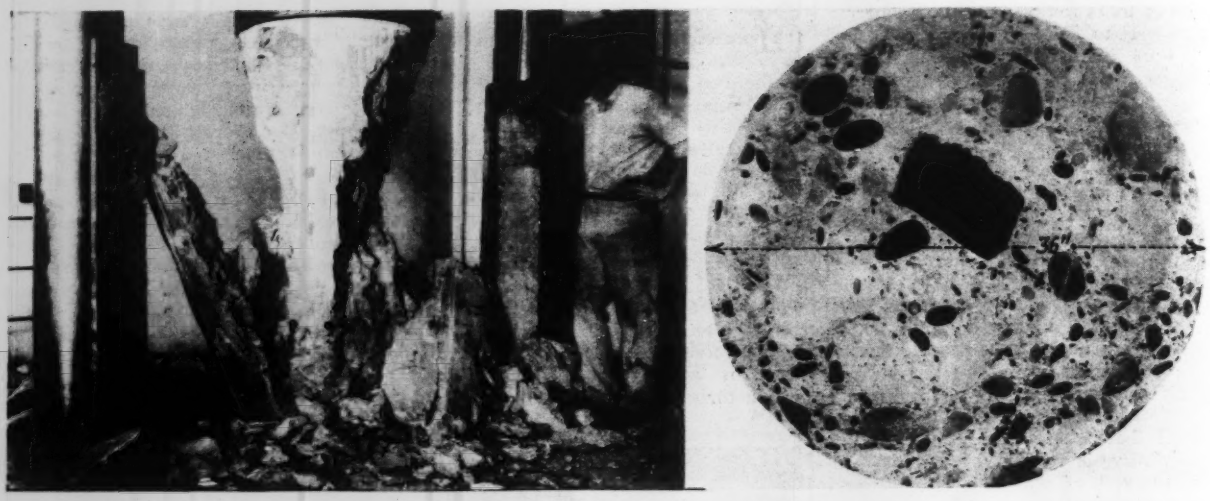


Fig. 5—Test of the mass mix including 9-in. cobbles in a 36x72-in. specimen (left) and a sawed surface typical of the mass concrete (right).

tural details are modified to permit greater movement between the anchor posts. This check-up of contraction-joint opening is not as comprehensive as the one made at Owyhee Dam, but it is believed sufficient to establish the order of width of joint opening up to the time of and during grouting operations. Contraction joint openings of the order of $\frac{1}{8}$ in. are already visible in galleries in the lower part of the dam. To date, the results of the cooling operations as measured by the apparatus agree with the calculated results remarkably well.

How the contraction joints are grouted

After the concrete in each 50-ft. vertical layer is cooled to the desired temperature, the cooling slot in the center of the dam will first be filled with concrete, and then the radial and circumferential contraction joint openings, in that order, will be filled with neat cement grout of varying proportions suited to the particular conditions encountered. This is to be accomplished through a system of pipes buried in the concrete adjacent to each joint and having outlets at intervals on the face of the joint. The area of joint served by each such outlet is 50 sq. ft. on the circumferential joints and 30 sq. ft. on the radial joints.

Experimental results of grouting fine cracks under accurate control indicate that grout films of excellent quality can be produced—the excess water being forced into the concrete—and that good coverage of the surface of the joint is possible for any joint opening more than 0.01 in. in width. Field cores drilled from across contraction joints in Gibson Dam, Montana, indicate that where the crack is wide enough to secure good coverage the film is of excellent quality.

The necessity for producing a crack of sufficient width for grouting purposes, without causing so much shrinkage in the mass as to produce cracks at other than regular contraction joints, is largely responsible for the block, or column, layout designed for Boulder Dam, and also for the stipulations regarding heat of hydration in the specifications for the purchase of special cement.

Experience in both the laboratory and the field has proved that for grouting fine seams the cement must be screened just prior to use if clogging of the seams is to be avoided. For this work vibrating screens covered with 200-mesh cloth are being installed, and the screened cement will be stored in four-ply paper bags to prevent hydration from exposure to the atmosphere. The storage period after screening will be limited to seven days.

The creation of a desirable film of grout in the contraction joint requires: (1) grout of the proper consistency to flow into and completely fill the joint opening; (2) time for the cement in the grout to settle out in the joint so as to give a film of desired density for proper consolidation under pressure; and (3) sufficient pressure to consolidate further the film and drive excess water into the mass concrete.

Conclusions

In the selection of aggregates, in the stipulations in regard to concrete plant, in the design of the mix, in the use of a blended low-heat cement of controlled composition, in the requirement for bottom-dump buckets and in the provisions relative to placement and curing, the uppermost thought in the construction of Boulder Dam has been to produce mass concrete of greater durability than any heretofore placed by this bureau.

Experience to date seems to warrant the following conclusions relative to mass-concrete construction for Boulder Dam:

1. That the structural qualities and gradation of the aggregates are the best ever obtained in a dam built by this bureau.

2. That the contractor's plant for the production of concrete is probably superior to any ever used on similar work.

3. That the net effective water-cement ratio (about 0.53 by weight for the special cement) is as low as conditions on the job warrant for the satisfactory placement of mass concrete of 1 bbl. per cu. yd. cement content.

4. That the strength obtained in the mass as tested in 36x72-in. cylinders (2,500 to 2,800 lb. per sq.in. at 28 days, moist-cured at 70 deg. F.) is ample for any stress condition that may result.

5. That a slump of about 3 in. in the forms is resulting in a more uniform product than would be obtained with a lower slump under the job conditions encountered.

6. That the special cement now being purchased and blended at the dam site has aided materially in securing a concrete that meets the exacting requirements of this work.

7. That in placing mass concrete in large units the use of a bucket having two or more compartments or one in which the amount discharged at any time could be controlled would result in more satisfactory and economical placement.

8. That in placing mass concrete containing cobbles the internal type of vibrator serves to effect a more satisfactory job of placement around the forms, especially when an occasional dry batch is encountered, than can otherwise be obtained; but that the vibrator as ordinarily used in the field of mass-concrete placement is more a tool for transportation by flow within the mass than a means of super-consolidation.

9. That watertightness of the dam as a unit is principally dependent upon the thoroughness of the clean-up and curing and bonding of the new to old concrete at the horizontal construction joints.

10. That uniformity, as in all other mass production, is the most important factor in the entire manufacturing process, and that all stipulations relative to the mix and the making should first give due regard to the effect on uniformity.

Million Yards of Concrete Placed at Record Rate

Elaborate cableway system transfers 8-yd. bucketloads to the columnar blocks forming mass of dam—Multiple use of individual forms for each column—Installation of cooling pipes complicates pouring—Aggregate and mixing plants function smoothly

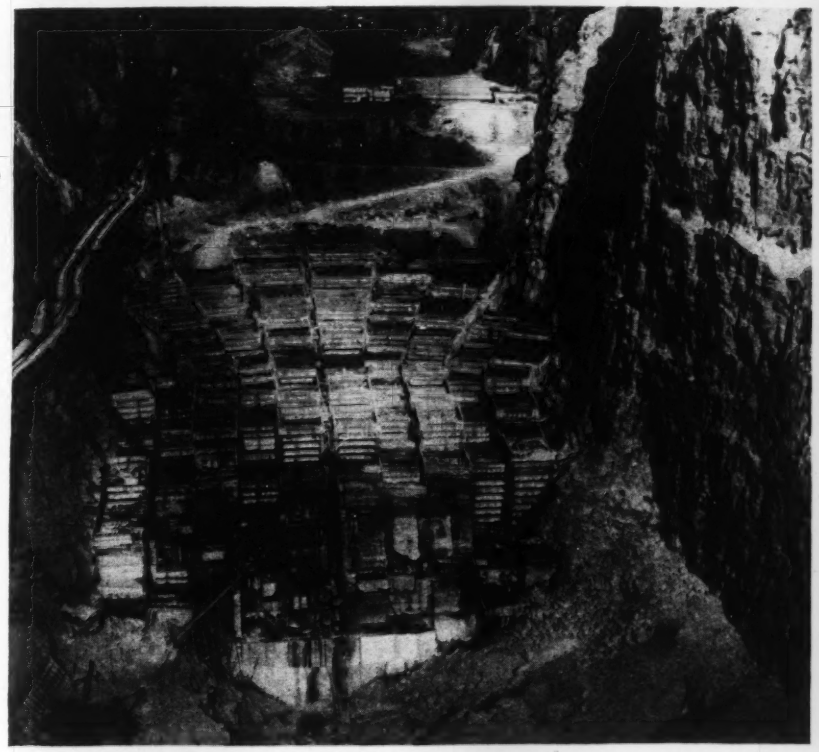


Fig. 1—Foundations of the barrier that will block the Colorado. About 32,000 cu.yd. of concrete are required for each 5-ft. lift of the dam at this stage of construction. Concrete reaches the dam via the double-track railroad hugging the left canyon wall. Five cableways distribute concrete to the forms in 8-yd. buckets.

AGAIN shattering all existing records and precedents, as in the case of the preliminary operations, placing of 1,000,000 cu.yd. of concrete at Boulder Dam has gone forward at an average rate of more than 6,600 cu.yd. per day, and during the month of October 204,000 cu.yd. was placed. The maximum day's record for concrete placed in the dam proper is 7,883 cu.yd. At the main mixing plant in the canyon the four 4-yd. mixers discharge 16 cu.yd. of concrete every 3½ min., with a 2½-min. mixing period, and are operated by a crew of only eight men. Following a train haul of 4,000 ft., the 8-yd. buckets are swung out over the dam and into position for placing by a system of cableways with a precision and speed that is especially notable considering the personal element and the operators' skill involved. The concrete, which was described as to its development and characteristics in the preceding article, is now traced from the mixer to the forms, together with an outline of the equipment and operations of the contractor's program.

General program

The concrete-placing program for the dam proper had to be arranged to cover the maximum dimensions of 660 ft. between faces and about 1,180 ft. along the curved crest. The dam is being constructed in the form of interlocking vertical columns, the joints between which are to be grouted. The size and arrangement of columns are shown in Fig. 2.

In this design the columns vary in size from 55x60 ft. near the upstream face to 25x30 ft. at the downstream face. The average area of the columns is about 36x40 ft. (1,430 sq.ft.). Considering a 5-ft. lift per column as the unit of concrete-placing operations, as it involves such common elements as form-raising, layout grouting and cooling pipes, clean-up and preparation, the number of the individual operations required is greatly increased over the number ordinarily necessary in building dams. The coordinates of the corners of each column remain constant from bottom to top, which permits repeated use of the forms in the construction of individual columns.

Plan to El. 720—The present concreting procedure, which will continue up to El. 720, the height of the cofferdams and the level of the railroad line from the mixing plant can best be outlined by describing the area now under placement (Fig. 1) and the reasons for maintaining the sequence of block raising. Preliminary placing operations during the first few months, in common with all construction operations, were not up to the present standard, being delayed by the establishing of the regular forms, the narrow width of the central section of the canyon limiting the number of blocks that could be poured and the installation of the cableway system.

The specifications allow a maximum vertical difference of 35 ft. in the top surface of the blocks. Further, the elevation of the rows of blocks (from up- to downstream face) is to be maintained in the same relative position. Thus, under present operations, the two rows of blocks on either side of an 8-ft. central slot, which contains the cooling pipe headers, are kept high, the next rows on either side are relatively lower, and so on, alternating to the abutments. Again, in each of these rows alternate blocks are maintained higher than others. An appreciation of this stepped system and its maintenance is important in following the form arrangement and the concreting procedure.

The high blocks of the high rows are commonly referred to as "leading blocks" and, of course, are formed on all four sides. The next lower blocks of the leading rows are maintained two lifts (or 10 ft.) lower and require forms only on the two sides, the up- and downstream faces being poured directly against the concrete in the leading blocks. The leading blocks of the low rows are formed on the up- and downstream faces and, lastly, the lowest blocks in the lowest rows require no forms at all, and each lift is placed against concrete on four sides. If there is no interruption in the placing schedule, the relative elevation of a group of blocks is that shown in Fig. 2. A field check is made each morning, so that all blocks that are out of step can be brought to proper elevation.

As the surface of the dam is raised, abutment blocks are continually being started. These, theoretically, begin

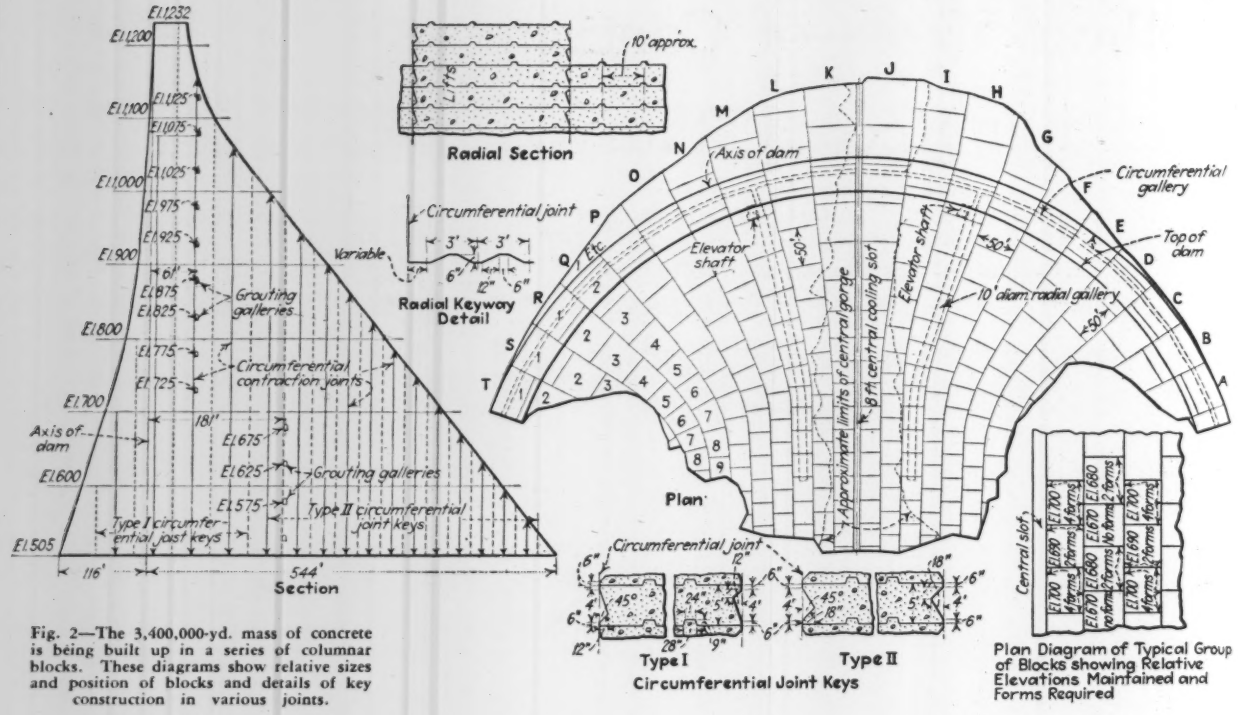


Fig. 2—The 3,400,000-yd. mass of concrete is being built up in a series of columnar blocks. These diagrams show relative sizes and position of blocks and details of key construction in various joints.

with a feather edge, which is actually widened out, and gradually widen as the abutment slopes back until they reach full size. Final stripping of the abutments in connection with these blocks requires the removal of loose rock and the usual clean-up just prior to pouring the lift. This final removal of rock averages 1 ft. in thickness. The contact between the concrete and the rock is provided with grout outlets similar to those in the construction joints in the dam. These pipes are continued up and the outlet boxes established along the rock line just prior to each pour.

The present area of pour is roughly 400 ft. long on the upstream face, 300 ft. along the downstream face and 500 ft. in the radial direction, containing about 165 blocks. The average time required to pour a 5-ft. lift in a 25x30-ft. block is 1½ hours. Even though concrete placing is always under way on two or three blocks at once, the pouring area is large enough to permit continuous placement of concrete despite the requirement of waiting 72 hours between subsequent pours on the same block. This area represents a concrete volume of about 32,000 cu.yd. per 5-ft. lift, and the yardage will remain constant for several months with the up- and downstream distance decreasing to compensate for the increasing width in the other direction.

Above El. 720—When the height of the dam has reached El. 720, the railroad line from the low-level mixing plant will have to be stopped at the upstream face. This will mean that the buckets of concrete cannot be handled directly by the cableways from train to point of pour, except for blocks near the upstream face. Otherwise, the cableways would have to transfer loads and operate with head-tower travel, which would be a slow process. To overcome this difficulty, a different operating program is required for the next 230 ft. up to El. 950, at which height storage will be started in the reservoir and the operation of the low-level mixing plant discontinued.

A large steel stiff-leg derrick, with a 136-ft. boom, operated by a 500-hp. hoist, will be constructed with its base at the level of the intake-tower foundation on the Nevada side of the canyon. This derrick will pick up the concrete buckets from the end of the railroad track at the upstream face of the dam, pour a few adjacent blocks directly and transfer the buckets to cableway No. 6, the second of the upstream pair of cableways (Fig. 3). Cableway No. 5 will pick up the buckets direct from the railroad trestle as before. The two cableways on the downstream half of the dam will be served from the high-level mixing plant.

When concrete reaches El. 950, the low-level mixing plant and the railroad will be eliminated by the beginning of storage in the reservoir, and above this elevation the high-level mixing plant, augmented by two additional mixers to its full size of four 4-yd. units, will be used with the present cableways to complete the dam and other structures.

Preparing concrete

Aggregate Plant—The design and operation of the aggregate plant has not been materially changed since it was described in *Engineering News-Record*, June 2, 1932, p. 783. It has continued to prepare the four sizes of coarse aggregate by dry screening, using water only for washing sand. Although the designed capacity of the plant is 500 tons per hour, it has produced as high as 700 tons for extended runs.

Cement Handling—To eliminate any variation in color and chemical characteristics of the cements received from the four producing plants in southern California, a blending plant was erected at the site of the high-level mixing plant under a separate contract. The operation is designed to provide a cement going into the dam, which will maintain, in general, the same proportion of cements supplied by the mills. The cement from each plant is stored in a separate silo and removed by a screw-conveyor system in a predetermined proportion. Action of the screw conveyor provides the mixing operation. From the blending plant the cement is pumped to the two mixing plants.

The pumping distance to the high-level plant is only about 100 ft., but the line to the low-level plant in the canyon is 5,700 ft. long with a 510-ft. total vertical fall in that distance. The rated capacity of this 9-in. line is 450 bbl. per hour, but actual capacity has often exceeded 550 bbl. One pump station is located at the beginning of the line, and a second is at mid-point where the line reaches canyon-floor elevation. Each of these plants is rated to consume 2,000 cu.ft. of air per minute which is sup-

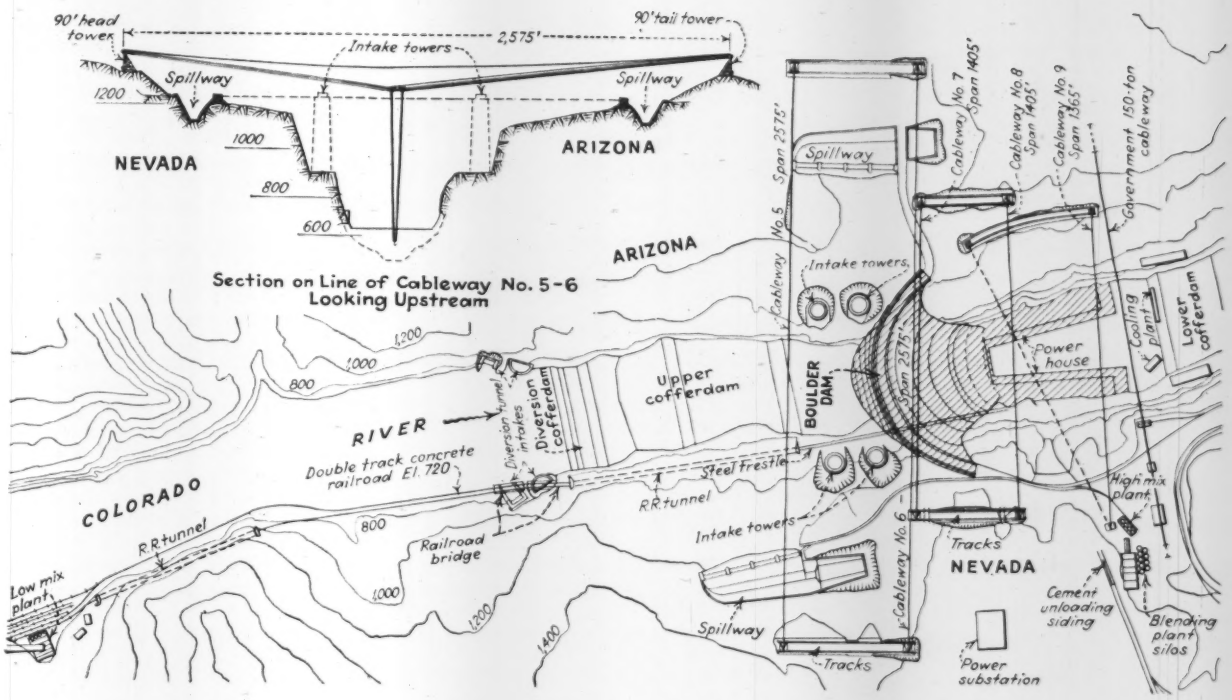


Fig. 3—Layout of cableway system used for handling all forms and concrete for the dam, spillways, intake towers and power house. With the exception of the 150-ton unit, the cableways are to be used for the construction period only.

plied from the permanent compressor air system.

Mixing Plants—The batching equipment and operation at the main mixing plant in the canyon about 1 mile upstream from the dam site were described in *Engineering News-Record* April 14, 1932, p. 534. This set-up is at present duplicated at half size at the high-level mixing plant. The mixer installation consists of four 4-yd. units at the low-level plant and two at the upper plant, although plans call for doubling the capacity of the upper plant soon. The batching equipment is designed to operate both manually and automatically. The producer of the equipment, recognizing the unprecedented character of a completely auomatic batching installation, provided the alternative of manual control. However, the automatic control has functioned with little difficulty and is being used exclusively at a considerable saving of labor cost at the plant.

The crew at the low-level plant, which turns out more than 2,000 cu.yd. per shift, consists of one man at the track hopper where the aggregate cars unload, one conveyor-system oiler, two men at the aggregate hoppers over the plant, one man at the batchers, two mixer operators for the four mixers and one mechanic for the conveyor system. At the high-level plant the crew is the same, with the elimination of the conveyor mechanic and track hopper man, as the plant has a gravity feed from the aggregate trains.

Careful time studies show that the time required for loading and discharge of the mixers averages 50 sec. With the present 2½-min. mixing period, the complete cycle of operation for the 16 yd. of concrete is about 3 min. 20 sec. Slump of the concrete as placed is required to be about 3 in. As loss in slump from mixing plant to point of bucket discharge averages 0.6 in., the slump of the concrete when mixed is 3.6 in. Details of the mix are covered in the preceding article.

Train Haul—From the mixing plant to the cableways at the dam the concrete buckets are moved for 4,000 ft. by single-car trains consisting of a standard-gage flat car pulled by an electric locomotive equipped for both battery and third-rail operation (Fig. 4). This locomotive arrangement has the advantage of eliminating the third rail around the plant and crossings and, at the same time, removing the peak loads on the direct-current generating station. The cars are built up with a steel superstructure that provides four compartments to dock buckets. These pockets are open on the canyon side (Fig. 4) to facilitate getting the buckets in and out with the cableways. On the move to and from the plant the cars always carry two buckets in alternate compartments spaced to match the direct discharge from the mixers.

A double track (Fig. 3) extends from the plant to the dam at El. 720, the crest of the cofferdams. This route required the driving of two 1,000-ft. double-track tunnels and a bridge of two 135-ft. steel-truss spans to cross the upstream portals of the Nevada diversion tunnels. In the dam site proper the tracks are carried along the canyon wall on one-leg steel trestle bents. Running time for loaded trains is about 3 min. to the dam, averaging 13 m.p.h. Seven trains are operated, and there is no delay at either terminal.

Arriving at the mixing plant with two empty buckets in alternate compartments, the train runs under the mixers and receives two 4-yd. batches to half fill each bucket. It then moves immediately under the other mixers and finishes loading. The first pair of mixers is reloaded at once, and by the time the next train moves into position the next batch is ready.

Buckets—The design of the 8-yd. bottom-discharge buckets (Fig. 6) was the work of F. T. Crowe, general superintendent for the contractor. The bucket is of all-welded construction of ¼-in. steel plate, 6 ft. in diameter and 8 ft. high. The bottom consists of two semi-circular doors, hinged at the sides. Cables for handling the loaded buckets hook to long lines attached directly to the doors. As an additional safety measure, there are two catches which lock the doors closed and would not permit them to open, even though the load were inadvertently shifted to the other cables. The other line is attached directly to the top of the bucket. Each of these hoisting cables runs through spreaders to sheaves supported by a four-part line.

In operation, the two hoisting lines are coupled to the bucket and the load picked up by the cable attached to the doors. When lowered to the surface of the concrete at the point of pour, the safety latch either releases automat-

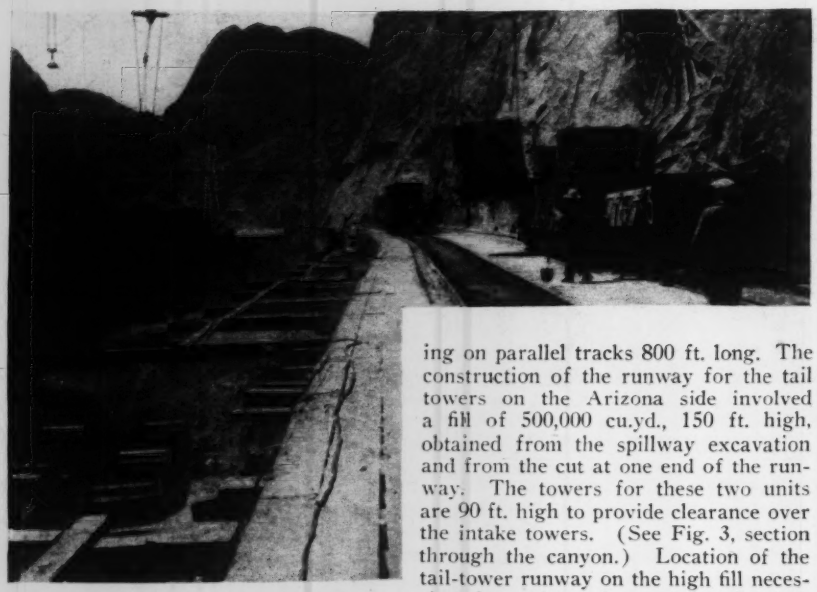


Fig. 4—Arriving at the dam, the buckets are picked up and moved to the forms by one of several cableways. The screen is for the protection of men below.

ically or is tripped by hand. The take-up is then made on the lines attached to the top of the bucket, which literally picks it up from around the concrete. After the bucket has been lifted well clear of the forms, the cableway operator shifts the load back to the door lines again, which closes them and sets the safety latch. On return to the train the lines are removed and shifted to the next bucket.

Cableways

To solve the problem of handling concrete and materials in the canyon, meeting the necessary requirements of speed and flexibility, the contractor selected a system of five cableways spanning the canyon. The general layout of this system and its coverage of the dam and power-house sites is shown in Fig. 3. The two longest units, designated as Nos. 5 and 6, required a span of 2,575 ft. to cover the two spillways. These two cableways are identical units with head and tail towers traveling on parallel tracks 800 ft. long. The construction of the runway for the tail towers on the Arizona side involved a fill of 500,000 cu.yd., 150 ft. high, obtained from the spillway excavation and from the cut at one end of the runway. The towers for these two units are 90 ft. high to provide clearance over the intake towers. (See Fig. 3, section through the canyon.) Location of the tail-tower runway on the high fill necessitated provision for occasional rebal-lasting of the track and allowance for slight irregularities in rail grade. The wheel truck frames are mounted with ball-and-socket connections under each tower for equalizing the loads. The cable pull is taken through the tower to horizontal wheels running against a timber member that is adjustable for slight irregularities caused by settlement and is anchored to concrete dead-men buried in the fill.

Cableways Nos. 7 and 8 have spans of 1,405 ft. and operate on concentric radial tracks. Again, the required location of the two tracks presented problems: the Arizona runway includes a cut about 100 ft. deep and the head-tower track on the Nevada side required a deep cut and sections of steel trestle to bridge low points. Cableway No. 9 is a radial unit with a fixed head tower on the Nevada side, a span of 1,365 ft. and an 800-ft. length of track on the other side of the canyon. This cableway covers most of the power house area and extends to the 150-ton permanent cableway of the government described in another article in this issue.

All of these five units of the contractor's cableway system are standardized in as many mechanical features as possible. They all have a rated capacity of 25 tons with some allowance for occasional overload. Head towers and all operating equipment are located at the Nevada side (Fig. 3). A 3-in. locked-coil track cable is used, with provision for periodic rotation to equalize wear. The cables have a breaking strength of 550 tons and operate with a loaded deflection of 6 per cent. The endless rope is 1 in. in diameter, and the hoisting lines are $\frac{7}{8}$-in. in diameter.

The main hoist for each cableway is run by a 500-hp. motor equipped for regenerative braking, magnetic reversing control and counter-torque deceleration while lowering. The hoisting speeds are 300 ft. per minute for raising and 420 ft. for lowering. The track carriage has a maximum speed of 1,200 ft. per minute. For moving the towers along the runways, a 100-hp. motor is provided in each tower; they are moved by properly synchronized remote control at a speed of 50 ft. per minute through a three-part line. Air for operating brakes and clutches is provided by motor-driven compressor units in each head-tower hoist house. The cableway operator, in every case, is located in the head tower and cannot see the load, which is being directed entirely by bell and telephone signal.

The cableway layout, design of the towers and the erection of the entire system was carried out by Six Companies, Inc. The cableway operating units including hoists and carriages were furnished by the Lidgerwood Manufacturing Co.

Forms

Aside from the radial and circumferential keyways (Fig. 2), the form system used for the dam consists of

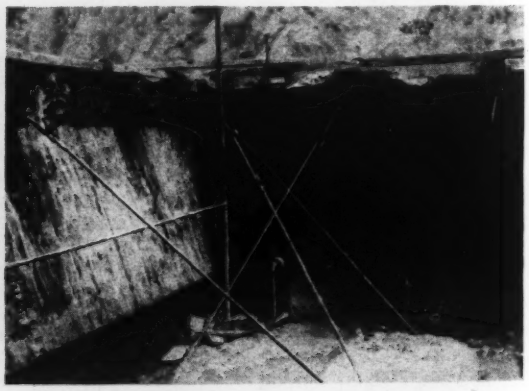


Fig. 5—Details of forms fastenings: Cooling pipes are laid on the surface (left) immediately before the lift is placed. She-bolts and hooked rods (center) embedded in the top of the lift provide for holding the cantilever forms for the next lift. Outlets for the grout system are nailed to the forms. Note the keyways produced by the forms.

metal-lined wooden panels of the usual cantilever type, providing for a 5-ft. lift, with the vertical timbers extending down another 5 ft. against the last pour. In addition to cantilever action, the forms are partly tied in at the top. Near the top of each pour she-bolts are left in the form with hooked bars (Fig. 5) that are buried in the concrete. When the form is raised, these bolts, at 3-ft. spacing, are used as the main support for the cantilever action, with the timber tail pieces bolted to the next lower row.

The corners of each of the columnar blocks of concrete in the dam extend vertically from the lowest point of the block to the top. This design feature permits forms to be designed and built for each separate block and used for successive lifts without recutting. The limit of re-use has not been determined, but some of the forms have been moved up for as many as 30 lifts with only minor repair to damage caused principally by the buckets.

The forms are lifted by steel loops left in the top, using two or three tripods and chain jacks. When first placing the forms in position, or if for any reason it becomes necessary to move a form laterally, it is done by a cableway using a spreader beam of timber. The top of each form section is capped with a 12-in. plank that is used as a walkway.

Concrete placing

Under present concreting procedure the buckets are delivered by train on the trestle along the Nevada canyon wall at El. 720 and handled directly by cableways Nos. 5, 6, 7 or 8. Each cableway delivers buckets to the same block for the entire 5 ft. lift, which eliminates interference and excessive moving of the towers. It also tends to speed cableway operation because the range of vertical and horizontal motion is repeated. There are usually three or four blocks under pour, in addition to some of the edge blocks handled separately by concrete from the high-level plant; clean-up operations, abutment preparation and form-raising are also going on at the same time.

The usual placing crew for each block consists of ten men and a foreman in the form (seven-man crew for small blocks), two signal men to direct the cableway operations and the two transfer men at the train. As soon as the full bucket is hooked on, the signal man stationed at the track directs it to be raised and started out over the dam (Fig. 4). After that the directions for the movements of the cableway are taken over by the other signal man stationed on the form, who is interconnected on the same telephone circuit. He directs the spotting, landing and discharge of the bucket. If the block is one on the Arizona side of the canyon, the trip is about 400 ft., and it is important to get the bucket out and back with minimum delay.

Fig. 6—Concrete buckets are brought to rest on the surface of the lift (left), which releases the safety catches, and the take-up is then made with the lines attached to the rim, which has an action of lifting the bucket off the concrete (right). Note the consistency and the details of the forms.

Directed by telephone orders from the signal man on the block, the operator moves the carriage on the track cable out along the cable at full 1,200-ft.-per-minute speed; the 20-ton load of bucket and concrete slowly gathers momentum on the end of the 500-ft. vertical line and starts swinging across the canyon. Based on judgment and practice, the signal man directs the carriage to be stopped about the center of the canyon and the bucket continues on its slow long swing like a huge pendulum. Finally, when it is almost directly over the block under pour, the carriage is again ordered forward and arrives directly over the bucket as it reaches the far point of the swing. So nicely is the timing done that in practically every case there is hardly any perceptible swing of the bucket as it comes to a stop under the carriage and over the block.

Then, with a little final maneuvering to put it in exact position for emptying, as directed by the foreman, it is lowered to rest on the concrete (Fig. 6). When each lift is started, the buckets are landed on the horizontal keys left on the preceding pour to eliminate crushing the cooling pipes. This is done until the concrete has reached a depth of about 18 in., when the bucket is allowed to be placed on any point on the block. When the bucket is lowered onto the concrete, the safety dogs automatically release or are tripped. The take-up is then made by lifting the bucket from the lines attached to the rim, and the doors open, discharging the 8-yd. batch as the bucket rises (Fig. 6).

As the load is released, there is a natural surge of the cableway, but the operator continues to take up on the line, and the rebound does not bring the bucket to within a dangerous proximity to either crew or form. As soon as the bucket is clear, the load is transferred back to the lines attached to the doors and they close, eliminating the possibility of droppings as it returns to the track. Direction of the returning empty bucket is again taken over by the signal man at the track who controls its landing.

Fig. 7—In the confined space of the abutment blocks that are not up to the full size, the buckets are too difficult to handle and concrete is placed with 4-yd. agitators.

The signal men directing cableway operations are mostly boys proved by a trial to have quick faculties and a natural sense of rhythm so essential to the efficient handling of the cableways. They are trained for the work by using a duplicate set of head phones and having them sit beside the regular signal man for a shift and listen to the orders given to the hoist operator.

As a result of the large 8-yd. mass and the 3-in. slump, the concrete moves into final position, following the raising of the bucket, without much handling. A little shoveling is done and the cobbles are pushed down. Vibrators are not used except occasionally near corners or around drain pipes and forms for galleries.

Original specifications called for depositing the concrete in 1-ft. layers over the block. Operations in the field proved that the surface of the concrete dried too rapidly between the deposit-

ing of these thin layers to make this placing possible. The plan now in use is to start at the downstream side of the form and deposit the entire 5-ft. thickness of the lift, letting the concrete take its natural slope in an upstream direction. Placing is then carried forward and finished against the upstream form. This procedure has the advantage of maintaining the concrete during pour on a slope up from the upstream face, also providing a wedging action against the upstream face of the form.

Curing—Each lift is finished off with 26x5½-in. horizontal keys 10 ft. apart. As soon as the concrete has taken its initial set, the surface is washed with an air and water jet. Before the next lift is placed there is another hosing accompanied by brushing and any necessary picking.

Curing water on the sides of the blocks is provided by sprinkling from perforated pipes attached to the bottom of the forms that move up for each succeeding lift. The top surface of the block is kept wet by hose sprinkling, and in the high temperature and low humidity of the canyon this becomes a problem of no small proportions. At times during the summer there were as many as seventeen men sprinkling the top of the blocks during the day shift and twelve on night shift. The water supply for washing and curing is obtained by pumping from wells in both cofferdams (river water filtered through these earth dams) and delivered to the dam. The waste water from these operations goes into the shaft sunk below foundation level and from there is lifted by pumps into a diversion tunnel. The iron content of this water produces a mahogany brown stain on the surface of the concrete, which tends to blend it into the natural rock of the canyon.

Cooling System—The unprecedented requirements of installing a system of cooling pipes in the concrete introduced problems that had to be solved by experience. The system of cooling provides header pipes extending up and downstream in the 8-ft. central slot at about 10-ft. intervals vertically, connecting with loops of small pipes extending to the abutments on either side. These loops of small pipes are placed between each 5-ft. lift of concrete and at about 5 ft. 9 in. spacing in the horizontal direction. The design principles behind this cooling-system provision were outlined in the preceding article, and the description of the refrigerating plant and the operation of the system are described in the following article. The method of installing the pipes in the concrete needs a brief explanation.

The 1-in. O.D. tubing that was finally adopted as the pipe for the loops in the concrete (original plans called for 2-in. standard pipe) were first installed by embedding them 1 ft. into the top of each lift after it had been placed. This method of installation resulted in considerable trouble and damage to tubing and connections. As a result, the system was changed and the cooling-pipe loops are now installed on the surface of the lift just prior to the placing of the next concrete. These pipes are laid in position and fitted together to extend between the side forms on the leading blocks. Connections are made with a coupling providing an expanding gasket that tightens around the end of the tubing as the nut on the end of the coupling is tightened. As an indication of one of the many minor problems involved in this new departure in dam construction, there was considerable trouble and study involved in securing the right type of gasket for this coupling. An aluminum-foil gasket was first tried, which proved satisfactory; but as an economy measure a change was made to a fiber gasket, which at first appeared to be satisfactory, but later was found to swell upon becoming wet, preventing insertion of the ends of the pipe in the coupling. As a final step, a rubber gasket was finally adopted.

The ends of the tubing are placed in 5-in. tin pie plates that are nailed against the outside of the form. When the form is stripped, these plates are left in place, and the ends of the tube are then available for connecting, as the succeeding blocks on either side are raised.

Huge Refrigeration Plant Reduces Heat of Hydration

Artificial cooling of concrete an innovation at Boulder Dam—Chemical heat dissipated by pumping cold water through 300 miles of 1-in. pipe — Two stages of cooling provide efficient and economical operation

THE BOULDER DAM PROJECT has been the scene of many an innovation in engineering and construction, but the scheme of artificially dissipating the chemical heat generated by the setting of 3,400,000 cu.yd. of concrete overshadows them all. To extract the heat of the hydrating cement from this mass of concrete, thereby reducing the temperature stresses and bringing the temperature of the dam to the ultimate annual mean within a relatively short period, permitting effective grouting, a large-size refrigerating plant has been completed and is delivering cool water through a pipe system embedded in the concrete. The dam design problems resulting from heating and subsequent cooling have been discussed in the preceding articles.

The present system provides a two-stage cooling operation using (1) water cooled by natural evaporation (average wet-bulb temperature is about 65 deg. F.) until the economic temperature differential is reached; and (2) refrigerated water at about 40 deg. There is only one cooling-pipe system, totaling 300 miles of pipe, embedded in the concrete; cross-valves allow the two supplies to be cut in and out. When the cooling has reduced the concrete temperature to the desired point, circulation is stopped and the level is ready for grouting. Thus in the general construction procedure the uppermost 35 to 50 ft. of the dam, measured from the highest block, will be under construction with the cooling-pipe system incomplete and natural dissipation of heat taking place from the sides of the blocks. In the next 50-ft. section below, the pre-cooled water will be in circulation, and in the next lower 50 ft. cooling is being further accelerated with the refrigerated water. For the 50-ft. level below, grouting operations would probably be in progress. This general scheme indicates roughly the probable sequence of cooling and grouting procedure. It is estimated that a twelve weeks' total period of circulation will be required for the two cooling supplies to produce the desired temperature in the concrete. This temperature would normally be the estimated mean annual of about 70 deg. on the downstream face exposed to the air, with the probable further refinement of cooling the upstream face to about 40 deg. corresponding to the reservoir water.

Original specifications

Specifications for the refrigerating plant and the cooling system covered by the contract were necessarily general as a result of the limited time available for preparation of the details and the unprecedented character of this design requirement. They called for a complete refrigerating plant capable of reducing the temperature of 2,100 gal. of water per minute from 47 to 40 deg. F. This plant was to be built in three units capable of individual or combined operation, and the capacity of the equipment was to provide for any

losses in plant or transmission to the actual cooling pipes. The requirement was to remove excess heat above 72 deg., starting at a minimum period of six days after concrete had been placed. It was estimated that the average temperature rise resulting from hydration of the concrete would be about 40 deg. F. above placing temperature. The providing of the cooling-plant system, including the cost of equipment, building and entire operation of the plant, was bid as a lump sum. The bid of the Six Companies Inc. for this item was $360,000.

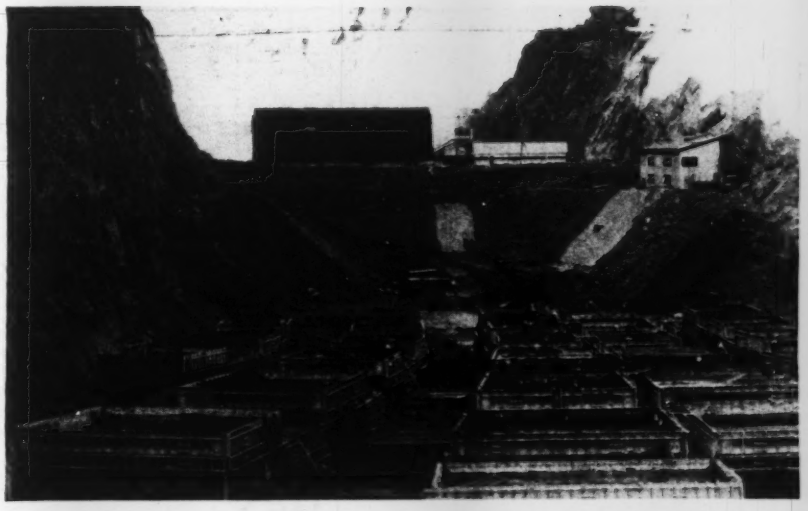
The cooling-pipe system called for in the original specifications provided loops of 2-in. standard pipe or tubing spaced at 10-ft. vertical intervals and about 11 ft. apart in a horizontal plane. It provided that the pipe, furnished by the government, should be cut, threaded and installed by the contractor to withstand a pressure of 100 lb. per sq.in. Specifications further provided that the size of pipe, spacing and amount of concrete to be cooled might be changed subsequent to the contract. This in general, covers the provisions for cooling as required by the original specifications. The following description outlines the plant and cooling system as now built and actually in operation.

Revised system

To provide a more flexible cooling system and at the same time a more economical one, the contractor has designed and built, with the approval of the government, a system which provides for (1) a cool-water supply of 70 deg. or less resulting from passing desilted river water over a cooling tower; and (2) water cooled by the ammonia refrigerating process to about 40 deg.

The plant is located on the Nevada side of the canyon on rock foundation above backwater elevation immediately upstream from the downstream cofferdam. This site was used because cooling will continue after storage in the reservoir and power-plant operation are started, which will require removal of the cofferdam. The cooling tower was built on the crest of the downstream cofferdam, about 200 ft. from the refrigeration plant. This unit did not demand the same permanence because when the cofferdam is removed an ample supply of pre-cooling water will be available from the power penstocks, and the cooling tower will no longer be required.

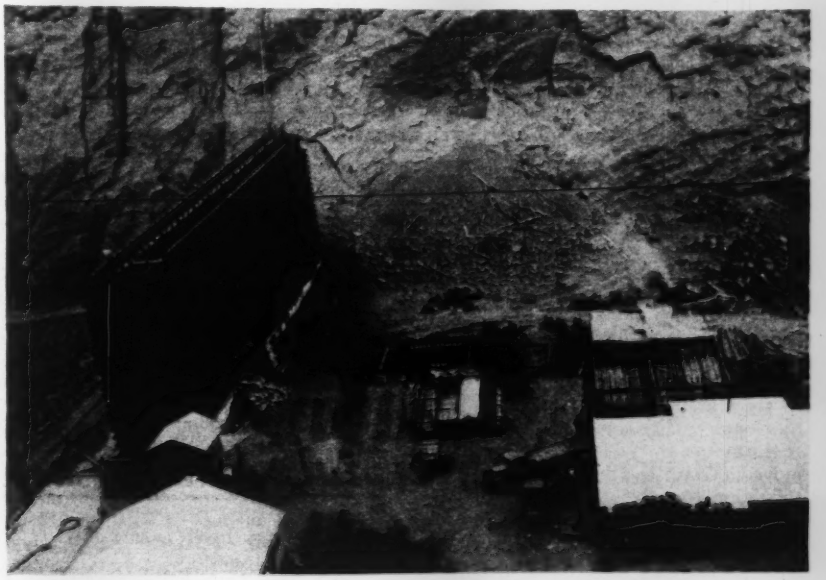
Plant—The capacity of the refrigerating plant is rated at 825 tons of refrigeration. This unit, commonly used in refrigeration practice, is equal to the amount of heat required to melt 1 ton of ice in 24 hours, or may be expressed as 220 B.t.u. per minute. The plant consists of three 275-ton compressors, which are remodeled air-compressor units used during the driving of the diversion tunnels. These units were purchased especially for this dual service and were adapted to refrigeration service by the simple substitution of ammonia cylinders for the original air cylinders. The plant layout will permit the addition of a fourth unit if necessary. The electric motors driving these compressors are 250 hp. each for the refrigeration work, and the motor size was also selected with this purpose in view, as normally they would have been of 200-hp. size for ordinary air-compressor service.



Refrigeration equipment for cooling of 3,400,000 yd. of concrete in Boulder Dam is located at bottom of the canyon just below the dam. Cooling tower for pre-cooling water for first stage of heat dissipation is shown at top center, located on the downstream cofferdam. After storage has commenced in the reservoir, this cooling tower will be dismantled. Refrigeration plant can be seen against canyon wall at extreme right.

The rated 825-ton capacity of the present plant, when reduced by an estimated loss of 50 tons in plant and pipe lines, leaves an actual plant capacity of 775 tons as compared to the original specification requirement of 620 tons.

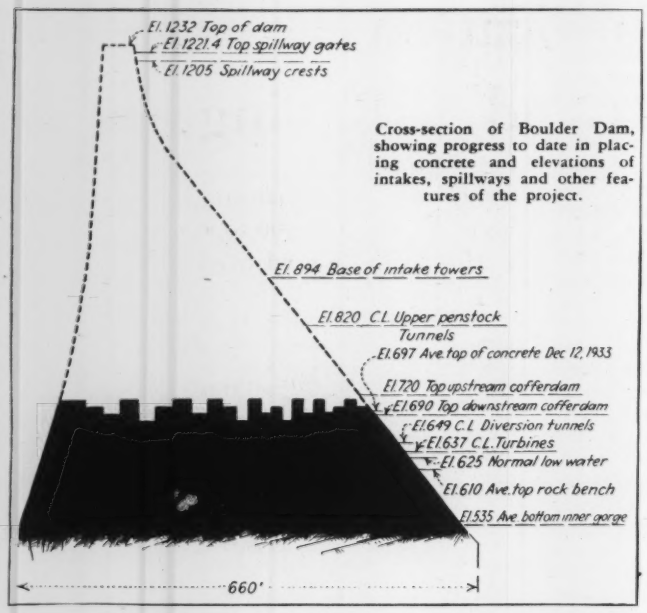
The atmospheric type of cooling tower erected on the crest of the cofferdam is built of redwood and is 150x16 ft. in plan and 43 ft. high. The Six Companies' specification to the manufacturer required it "to cool 6,000 g.p.m. from 87½ deg. to 80 deg. with a 75-deg. wet-bulb reading and a 5-m.p.h. wind velocity." The low humidity in the region, which runs about 12 to 15 per cent, coupled with the natural draft in the canyon, combine to make this method of cooling very effective. During the month of September it was possible to cool water as low as 65 to 70 deg. with this tower. Considering the volume of water and the relative



The cooling tower and header pipe yard, located on the crest of the downstream cofferdam, as seen from the Nevada wall of the canyon.

temperatures produced by this cooling tower, the pre-cooled system provides up to about 900 tons of refrigerating capacity in addition to the 825 tons produced in the plant.

Water supply for this entire cooling system was an important problem. After studying various possibilities it was decided to reduce pump maintenance and provide more continuous operation by recirculating the pre-cooled water rather than to waste it as it came from the dam. The wasting of such a flow on its return from the dam would have required the use of river water to make up the flow. On the other hand, in the present recirculating system it is possible to secure the small amount of make-up water from the sump between the cofferdams, providing a silt-free supply. The basin of the cooling tower was built especially large to provide a desilting action. During maximum operations of the entire cooling system there will be circulated over the tower 3,000 g.p.m. of the pre-cooled water and 3,000 g.p.m. of condenser water from the refrigerating plant.


El. 1232 Top of dam
El. 1221.4 Top spillway gates
El. 1205 Spillway crests
El. 894 Base of intake towers
El. 820 C.L. Upper penstock Tunnels
El. 697 Ave. top of concrete Dec. 12, 1933
El. 720 Top upstream cofferdam
El. 690 Top downstream cofferdam
El. 649 C.L. Diversion tunnels
El. 637 C.L. Turbines
El. 625 Normal low water
El. 610 Ave. top rock bench
El. 535 Ave. bottom inner gorge
660'

Cross-section of Boulder Dam, showing progress to date in placing concrete and elevations of intakes, spillways and other features of the project.

Pumping plant

In the closed, refrigerated water system the pumping plant consists of three 750-g.p.m. electrically operated centrifugal units and an additional stand-by unit to handle the 2,100-g.p.m. flow. The friction loss for the 50-ft. lift of cooling system is estimated at 130 ft. Since this system provides a closed circuit on the pumps, there will be no additional pumping head, except friction, as the system is raised for each successive 50-ft. lift of cooling.

The open pre-cooled system requires a more extensive pumping layout because of the increasing head as the cooling process is raised in the dam. For the initial operations, below El. 750, the pumping will be done with three 750-g.p.m. centrifugal pumping units (one stand-by is provided). Between El. 750 and El. 950 another duplicate system of pumps will be introduced to handle the additional head. When the dam has reached El. 950, storage is scheduled to start in the reservoir and the lower cofferdam and the cooling tower will be removed. With the dam above this height the reservoir water will be used for the water supply. With the head produced by the reservoir, the pumping installation is estimated to be able to handle the head to the crest of the dam. If water storage is not begun in time to provide sufficient head for the plant, another duplicate set of booster pumps will be added to this system. The water taken from the reservoir will be comparatively free from silt, and as a result of the unlimited supply the return from this system will be wasted into the river. In addition, the water required for the condensers of the refrigerating plant will also be taken from the penstocks and will be wasted into the river.

The water supplies from the pre-cooled and refrigeration systems will be pumped in two main 14-in. headers and two similar return mains from the plant about 1,000 ft. to the downstream toe of the dam. A central slot 8 ft. wide is left through the dam during construction to provide for the cooling-system header pipes. The four main pipes extend upward on the downstream face of the dam at the slot and are carried up as the dam is raised. From the main headers and return, 6-in. horizontal headers are extended into the slot to the upstream face hung on J-hangers attached to the concrete. The 14-in. and 6-in. headers of the refrigerating system are insulated with a 2-in. cork covering to reduce refrigeration loss.

In the lower levels of the dam the vertical spacing of the 6-in. headers is varied because of the smaller volume of concrete per foot of elevation in the lower part of the canyon. The lowest header serves a concrete depth of about 25 ft., and the next about 20 ft. Above this level the dam widens to the main canyon walls, the volume per foot lift is greater and the headers will be spaced at 10-ft. vertical intervals, to serve two layers of cooling pipes. It is possible that at the higher levels the spacing may be increased to 15 ft. as the volume of concrete decreases.

The 6-in. horizontal headers connect directly with the cooling-pipe loops in the concrete. These individual loops of 1-in. O.D. pipe run all the way from the central slot to the abutments and return. The connection between the header and the end of the cooling pipe is made through rubber hose capable of handling a 100-lb. per sq.in. pressure. The hose type of connection was used rather than pipe to make installation easier, reduce effect of vibration and make repairs easier in case of material falling down the slot and breaking connections. These hose connections fasten directly to the loops or tubing embedded in the concrete.

Pre-cooled water from the cooling tower was circulated through the lower lifts of concrete beginning Aug. 10, 1933. On Oct. 11 the refrigerating plant started operation, and that night it pumped 44-deg. water at the rate of about 1,000 gal. per minute into the two lowest headers, representing about a 50-ft. depth of concrete from the lowest foundation. This water returned to the refrigerating system at a temperature of about 74 deg. This represented the initial operation of the refrigerating plant, and only two of the three machines were in operation. For this initial output the plant was producing about 400 tons of refrigeration. As the plant operation continued the plant has delivered as high as 1,000 tons

FINANCIAL STATEMENT OF BOULDER DAM PROJECT, OCT. 31, 1933

Appropriations	
Act of July 3, 1930	$10,660,000
Act of Feb. 14, 1931	15,000,000
Act of April 22, 1932	6,000,000
Act of July 1, 1932	7,000,000
Act of July 22, 1932 (Emergency Construction Act, 1932)	10,000,000
Act of Feb. 17, 1933	8,000,000
Act of June 16, 1933 (allotment from Public Works)	38,000,000
Total	$94,660,000
Collections	130,068
Total available	$94,790,068
Cash disbursements	42,722,361
Treasury cash balance	$52,067,707
Investments (including outstanding obligations)	
Flood control, storage, etc., diversion works, dam, outlet works, etc.	$39,264,975
Power production	1,979,703
Railroad, highways, buildings, engineering, research, etc.	4,489,836
Boulder City and other physical property	1,275,531
Interest during construction	2,101,001
Investigations, Colorado River Basin	178,542
Total capital investment	$49,289,588

Penstock Fabrication by Welding and X-Raying

Steel slabs 2¾ in. thick are bent and welded into 30-ft.-diameter pipe at rim of Black Canyon—76 miles of welds on 45,000 tons of pipe inspected by X-ray—Stresses relieved in oil-fired oven

DESERT surroundings provide an incongruous atmosphere for the modern steel-fabricating plant that is producing the record-breaking penstock pipes for the Boulder Dam project. Located on the project principally as the result of transportation problems, the plant of The Babcock & Wilcox Co., which holds the $11,000,000 contract for fabricating and installing the penstocks, is well started on welding the 45,000 tons of steel into pipe sections varying from an 8½-ft. diameter and ⅝-in. thickness to the maximum of 30-ft. diameter with 2¾-in. thickness. The key to the plant production is the coordination of the output with the installation of the penstock tunnels, as a result of the extreme difficulty of handling and storing the large 30-ft. sections after fabrication. Many of the details of the steel-handling and welding technique are of unusual interest to civil engineering readers; in addition the steps in the process of building these important units of the Boulder Dam project form an integral part of the complete story.

The plant site was selected as the first location on the government railroad back from the canyon where a level space was sufficient for the plant and for the extensive storage yards necessary in storing the completed sections. This station, locally called Bechtel, is about 1½ miles back from the canyon rim and is below the last of the five tunnels on this railroad line. This position in relation to the tunnels was important in the matter of rail transportation to the site, but subsequent plans have provided for handling the completed sections, by special truck and trailer units, from the plant to the government cableway that will place them on the platforms at the portals of the construction adits.

The shop building (Fig. 1) is a steel frame and galvanized-steel-covered structure 520 ft. long, 85 ft. wide and 55 ft. high to chord of roof truss. The steel columns are spaced at 25-ft. intervals along the side, and their design involved heavy sections because of the great loads, in which a lift will be handled by two 75-ton cranes.

As a lean-to building on one side of the main shop, an area 150 ft. long by 20 ft. wide is provided to house the office of the shop, testing laboratory, machine shop, compressor plant and washroom. The main shop and lean-to involved about 750 tons of structural steel, 67,500 sq.ft. of galvanized-steel covering, 23,000 sq.ft. of glazed steel sash and 30,000 yd. of excavation. It is impossible to outline a formal layout of the equipment because many units are portable and are moved to take care of changes in the fabricating system resulting from working on different pipe sizes. The general description of the fabricating process, outlined in the following, indicates the relative position of the major units. Fig. 2 is a general view through the shop, looking toward the head end, with work under way on 8½-ft. pipe.

Adjacent to the shop is the office building, a single-story timber-frame building (Fig. 1). In addition to these buildings at the plant site, the contractor also constructed twelve four- to six-room houses and seven four-apartment buildings in Boulder City for the use of married employees. A 100-room dormitory completely equipped with air-conditioning in every room is also provided for this organization.

Plant operation and output is dependent upon the work of installation in the penstock tunnels because of the limited storage space available within reach of the heavy cranes capable of handling the large-size pipe. It is impossible to handle this pipe, with special sections weighing up to 150 tons, except with the shop cranes, which will run on extension rails 600 ft. beyond the end of the building. The smaller pipe sections can be stored and rehandled with standard locomotive-crane equipment, and the plant began operations on this size of penstock. This procedure had the advantage of allowing the plant operations to begin on the smaller-size material, which can be more easily stored until needed.

Since the work of installation must progress from the upper end of the penstocks, using the 30-ft.-diameter sections, fabrication of these pipes has awaited the lining of the 37-ft.-diameter penstock tunnels. This lining is now in progress on both sides, and it is estimated that in the spring of 1934 both 37-ft. penstock tunnels will be ready for the installation of the welded pipes. In the meantime the plant has fabricated practically all of the smaller-diameter 13- and 8½-ft. pipes for both the Nevada and Arizona sides of the installation. Work on the large-size sections for the first installation on the Nevada side is now in production.

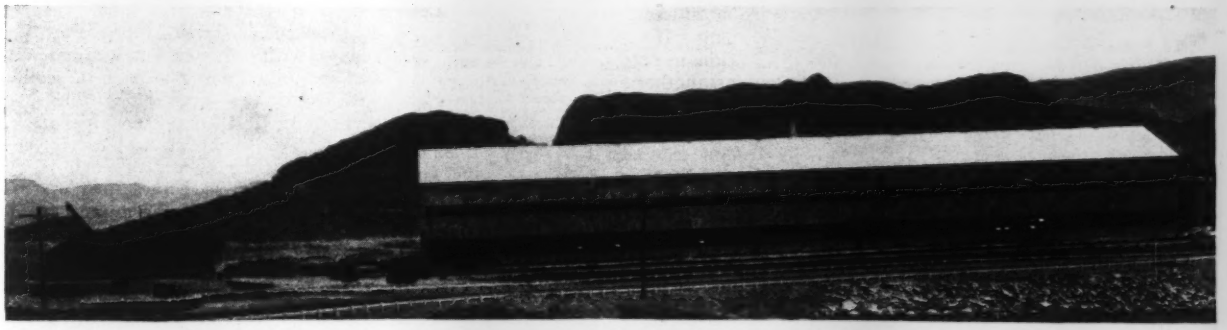


Fig. 1—Steel plate enters one end of this completely equipped fabricating plant in sheets and emerges at the other end as welded pipe sections, some of 30 ft. in diameter, thoroughly inspected and tested. Plant, located near rim of canyon, provides for straight-line operation. Pipe contractor's office building is at left.

Fabrication

Preliminary Steps—Steel is shipped in flat plates from Eastern plants; the largest plates are 32 ft. long by 12 ft. wide and 2¾ in. thick. These largest plates weigh about 23 tons apiece, and two of them constitute a freight carload. Three of them are fabricated into a 12-ft. length of 30-ft. pipe, and two such rings are welded together to form a single pipe section. The plate is unloaded by locomotive crane and stored in the yard at the west end of the plant.

Moved into the plant, the plates are handled throughout the fabrication process by two of three 75-ton electric cranes. Each plate is first laid out and marked to the required pattern, and the

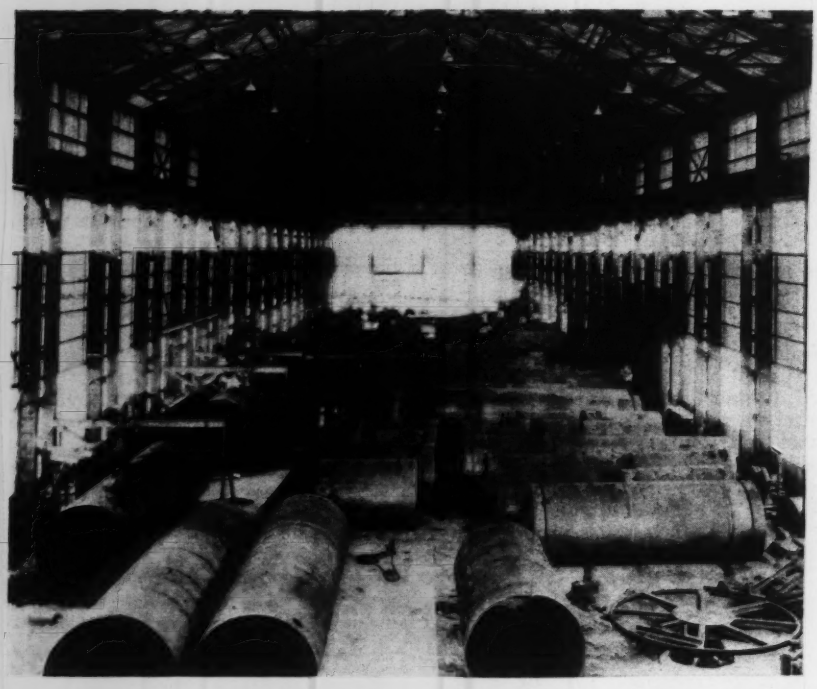


Fig. 2 (above)—Interior of shop during fabrication of 8½-ft. pipe sections, first to be built. View is toward receiving end of plant, with welding machines at left.

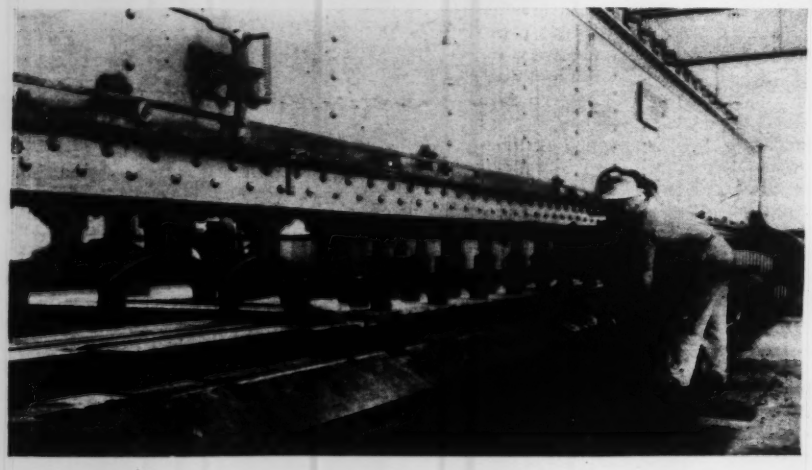


Fig. 3 (below)—Special planing machine trims edges of plates and cuts welding groove at the same time. Pneumatically operated plungers hold the sheets in place.

edges are then planed. The special planer (Fig. 3) for this work is equipped with a double set of cutters on the carriage for operating in both directions without loss of motion on the return. The plates are clamped into the planer frame by pneumatically operated plungers. This operation not only produces the planed edge but also provides the special outline of the edge weld.

From the planer the plates move to the vertical plate-bending roll, where they are shaped to cylindrical form. This roll is the most powerful ever designed for the purpose and can impose a load of 3,500,000 lb. on the plate. It will handle all the thicknesses and sizes of plate up to the 30-ft.-diameter section. The design and operation of this machine were described in *Engineering News-Record*, March 9, 1933, p. 307.

To form the special conical sections of pipe and to bulldoze the edges of the thick plates before starting them into the roll, two 1,500-ton presses are provided which work as a unit (Fig. 6). These presses are connected by cast-steel girders, weighing about 55 tons each, and they operate as a unit. The press equipment weighs about 300 tons, and the action is provided by a 30-hp. motor driving a rotary-pressure pump to provide oil pressure at 2,000 lb.

Welding—Following rolling, the plates are welded together, the number of welds and operations depending on the size of pipe to be fabricated. Preliminary steps consist of bringing the rolled sections to final shape and dimensions and spot-welding them, preparatory to placing them in the automatic machines. The welding space cut out by the planer provides the conventional V-shaped groove on the outside of the plate. The welding is done by automatic machines mounted on gantry units that operate either on the top or inside the pipe sections (Fig. 5). The pipe sections are mounted on rollers for turning to bring the one or more longitudinal seams under the arc or for welding the girth seams on the smaller diameter pipe.

The automatic-feed mechanism provides for a continuous operation on each passage of the arc. The flux-coated electrodes are provided in 12-ft. lengths for the machine; and as the ends are equipped with a threaded joint, the process is not interrupted by a stop to change rods. After each passage of the arc, the bottom of the weld is chipped clear of slag down to homogeneous metal before the next layer of metal is applied. Welding is done in accordance with the A.S.M.E. code for unfired pressure vessels, class I.

The 8½-ft. diameter pipes have a comparatively simple fabricating procedure, with only one longitudinal weld, and are joined into 20- or 30-ft. sections with one or two girth seams. The 20-ft. sections of 13-ft.-diameter pipe are required by specifications to have a stiffener at the center of each length, which will be used in supporting the pipes on the seats in the tunnel, leaving the joints clear for field connecting operations. This stiffener requirement permitted several possibilities of design, and the final arrangement provides a 1-ft. section of stiffener ring at the center, welded to two lengths of pipe. This stiffener ring is rolled separately from a special steel shape resembling the flange of a T-beam, with all but the start of the stem removed. In welding up one of these sections there are two girth seams required to connect the sections of pipe to the stiffener ring and, finally, the ring is completed by welding on what corresponds to the stem part of the T-beam. In assembling the pipe sections and the stiffening ring an elaborate system of spiders is used to bring the three into alignment before they are spot welded.

X-Ray—Following the completion of each welded joint, either a longitudinal weld or the subsequent girth seams, every inch is photographed by X-ray for inspection. This work will require the photographing and checking of more than 400,000 lin.-ft. of weld on this contract. The two 300,000-volt capacity X-ray machines are portable and are moved about to the welded pipe sections as required (Fig. 7). Beginning at a marked point on each longitudinal weld, the machine photographs a 30-in. section of weld and is then moved to the next position or, in the case of a girth weld, the pipe is rotated the equivalent distance.

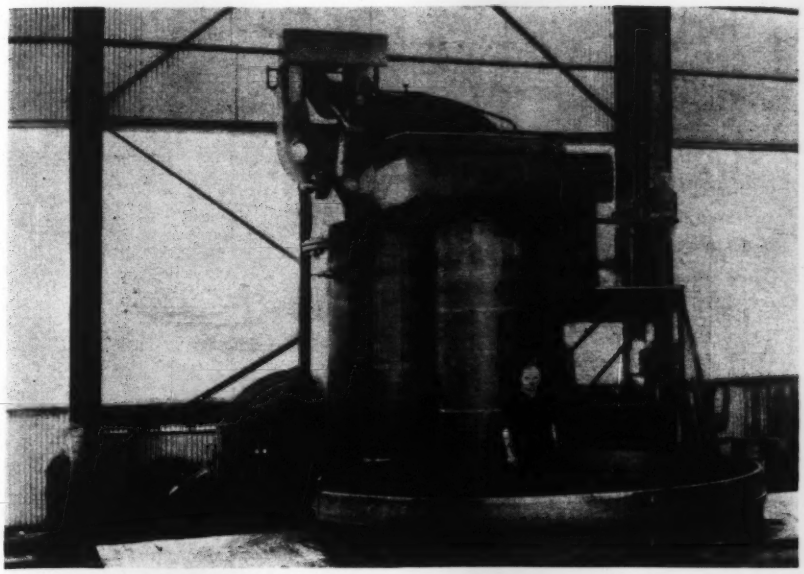


Fig. 4—Fabrication of the huge pipes requires this vertical bending roll, the largest ever built. The view shows rolling of stiffener rings for 13-ft. sections, which will be welded between two lengths of pipe. A ringed stem unit is later added to the stiffener ring to form a circular T-beam.

As soon as the X-ray of the particular weld is completed, the films are developed in the adjacent laboratory and inspected. This is done as promptly as possible, to insure approval of the weld before further work has been done on the section. In case the X-ray photograph reveals any flaw in the weld, it is chipped out and rewelded by hand.

Fig. 5—Automatic welding machine set up for longitudinal seam on a 30-ft.-diameter pipe section. The girth seams are made in the field with pins. Welding rods come in 12-ft. lengths with threaded ends for coupling into continuous rods, eliminating delay in changing rods. Two legs of spider used to shape pipe to perfect roundness before welding can be seen within the pipe section in the picture.

B. D. Glaha Photo

Stress-Relieving—After X-ray inspection of the welds and the approval of each section, the pipes are given a stress-relieving treatment by heating them to a temperature of about 1,200 deg. F. The specially built furnace is the largest of its kind, measuring 36x41 ft. in plan on the inside with a height of 28 ft. 3 in. The furnace is located at the end of the fabricating plant, and the door forms the front wall, moving out on rails to open. This wall-door combination also is integral with the car that carries the pipes as they are placed by the cranes. The furnace is operated as required by the output of the fabricating process. Its capacity will include sixteen sections of the 8½-ft. pipe, four of the 13-ft. pipe, and a single section of the 30-ft.-diameter pipe.

Heat is furnished by oil burners, and the hot gases are circulated through the furnace by a blower and valve system that reverses the flow on a timed cycle.

QUANTITY AND SIZE OF PENSTOCK PIPE

Length, Ft.	Diameter, Ft.	Thickness, In.
4,700	30	1 11/16—2 3/4
1,900	25	1 5/8—2 1/16
5,600	13	1/2—1 1/16
2,300	8½	5/16—5/8

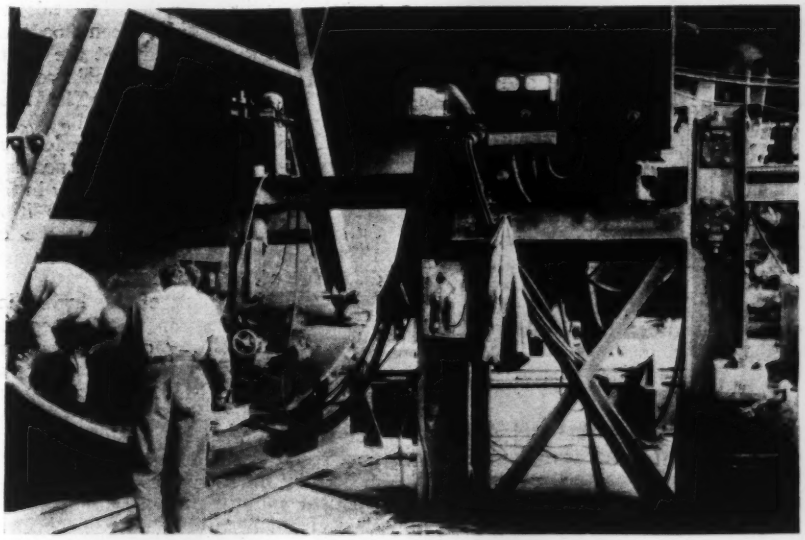
An automatic control can be set to reverse the gas flow at intervals of 1 to 10 min., but the usual run is made on about a 5-min. reversing period. The principle of reversed flow, first feeding the hot gas from one side of the furnace and then from the other, provides for equalizing the temperature of pipe being treated. The furnace is lined with insulating firebrick, including the necessary gas ducts, to provide minimum heat loss and minimum heat-storage capacity. The latter is important, as may be judged by the fact that at least one additional furnace would be required if ordinary firebrick were used. Fuel consumption is estimated at about 700 gal. of oil or less for the six-hour heating period, bringing the furnace up to the 1,200-deg. required heat, and about 35 gal. per hour for the subsequent soaking period. Automatic temperature control, with recording instruments within the furnace, maintains the temperature within 20 deg. of the desired point.

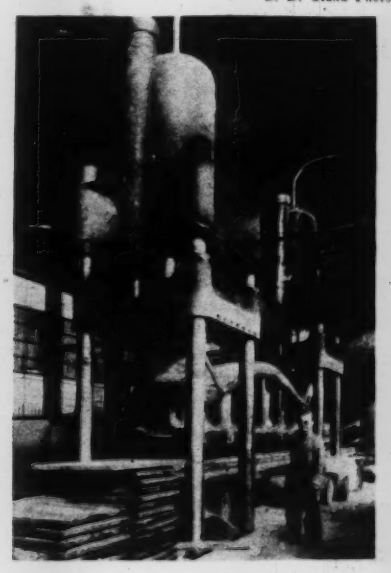
After the furnace, containing the pipe sections, has been brought to the 1,200-deg. point, this temperature is maintained for a period of time depending upon the thickness of pipe being treated. The furnace is then allowed to cool to a temperature of about 600 deg. during a three-hour period, after which the pipes are removed.

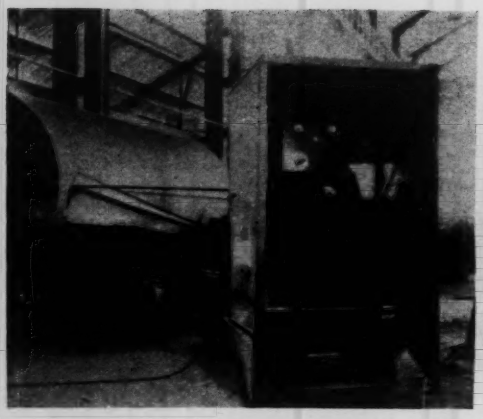
The final step is the accurate milling of the ends of the pipes to provide the final field fit. On the 8½- and 13-ft.-diameter sections this is done in the

Fig. 6—Heavy plates for the larger pipes are given initial bend by these two 1,500-ton hydraulic presses acting as a unit.

B. D. Glaha Photo







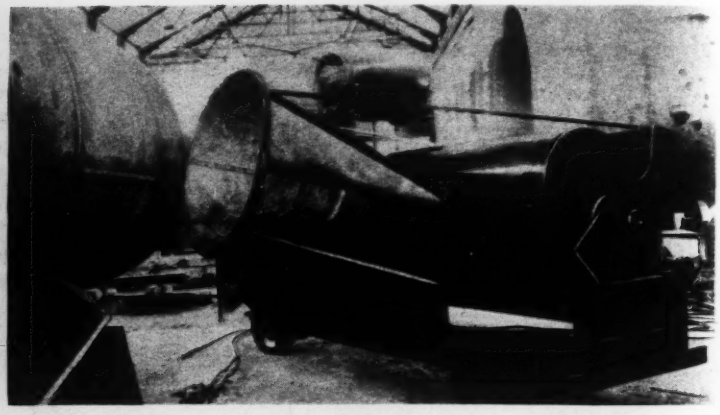


Fig. 7—Every inch of the 400,000 lin.-ft. of welds required in fabricating 45,000 tons of pipe is photographed by these X-ray machines for inspection. Welded seams are X-rayed in 30-in. lengths. Films are developed immediately after exposure to permit defective welds to be replaced before pipes leave welding frame.

storage yard with a motor-driven tool held by a spider in the end of the pipe section. The larger-size pipe will be milled with a large special lathe permanently mounted in the end of the shop.

Testing—One weld specimen is taken from each fabricated length of pipe and is tested in accordance with the A.S. M. E. boiler construction code, unfired pressure vessel section. This testing is done in a completely equipped laboratory, including a 300,000-lb. testing machine, adjacent to the shop, under the supervision of the government inspectors. Briefly, the tests include a tension test of the joint and a tension test of the weld metal itself, which are both required to equal that of the original plate. There is also a bending test, cold, which must show an elongation of the weld metal of at least 30 per cent without developing cracks. The specific gravity of the weld metal must equal 7.80 as a minimum.

The pipe sections are finally shot-blasted inside and given a primer coat of water-gas tar and a final coat of coal-gas tar applied hot.

As mentioned at the outset, the storage for these fabricated sections requires a large area, and handling is difficult. The first pipes to be installed are the largest-size, 30-ft.-diameter sections for the main penstock, but these sections can be handled only by the shop cranes. This made it impossible to fabricate them and store them in large quantities prior to erection.

Furthermore, there was the decidedly practical advantage of starting shop operations on the smaller sections, and this was done by completing all of the 8½-ft. and 13-ft. sections leaving the plant free to fabricate and handle the large sections as soon as the tunnel is available.

Spillways in Canyon Walls to Handle Floodwaters

Two side-channel outlets provide 400,000-sec.-ft. discharge capacity—Drainage system is important design feature—Automatic steel drum gates will hold reservoir level 24 ft. above fixed spillway crest

By D. C. McConaughy
Senior Engineer, U. S. Bureau of Reclamation, Denver, Colo.

DESIGNED to handle a discharge of 400,000-sec.ft., the two side-channel spillways for Boulder Dam will provide a capacity 50 per cent in excess of the great flood of 1884, which constitutes the peak runoff of which any tangible evidence remains. Further, this spillway capacity does not include the effect of 9,500,000 acre-ft. of reservoir capacity reserved for flood control or the 120,000-sec.-ft. discharge capacity of the power house and outlet valves. Each spillway has a 400-ft. length of weir crest and an over-all length of about 700 ft. from upstream end to the portal of the inclined discharge shaft. The two contain about 150,000 cu.yd. of concrete and required excavation of 700,000 cu.yd of rock Discharge of each is through an inclined tunnel, varying from 50 to 70 ft. in diameter, to the present diversion tunnels, which will act as permanent spillway outlets. Four 100x16-ft. steel drum gates on each spillway will provide automatic regulation to hold the reservoir level 24 ft. above the fixed crest of the weirs. Principal features of design, operation and construction are outlined in the following.

Design

The need for accurate and conservative spillway design can be appreciated from the fact that the reservoir will store 30,500,000 acre-ft. of water and raise the surface level about 600 ft. above the original river channel. In this reservoir 9,500,000 acre-ft. of capacity will be reserved for flood control, and the combined outlet capacity of the power-house openings and the outlet valves will equal 120,000 sec.-ft. Requirements for spillway capacity were based primarily on a study of the 1884 flood. It is estimated that this maximum peak was from 250,000 to 300,000 sec.-ft. compared to an average annual peak of about 100,000 sec.-ft. Studies of flood probabilities indicate that intervals of 200 years will occur between floods of the 1884 peak flow, and that the interval between floods of comparable volume may exceed 1,000 years. The final designed spillway capacity of 400,000 sec.-ft. is in addition to the capacity of the power-house outlets and the ponding effect of the flood-control capacity in the reservoir. With these provisions it is estimated that a flood similar to that of 1884 would be reduced to a maximum discharge of 75,000 sec.-ft.

A detailed account of the hydraulic-model testing program that formed the basis of the spillway design was presented in *Engineering News-Record*, Aug. 10, 1933, p. 155. Characteristics of the site indicated the feasibility of the side-channel type of spillway, and the final result of the design studies supplemented by the model tests provided two identical spillways, each with a 400-ft. clear crest length (Fig. 2). The channel

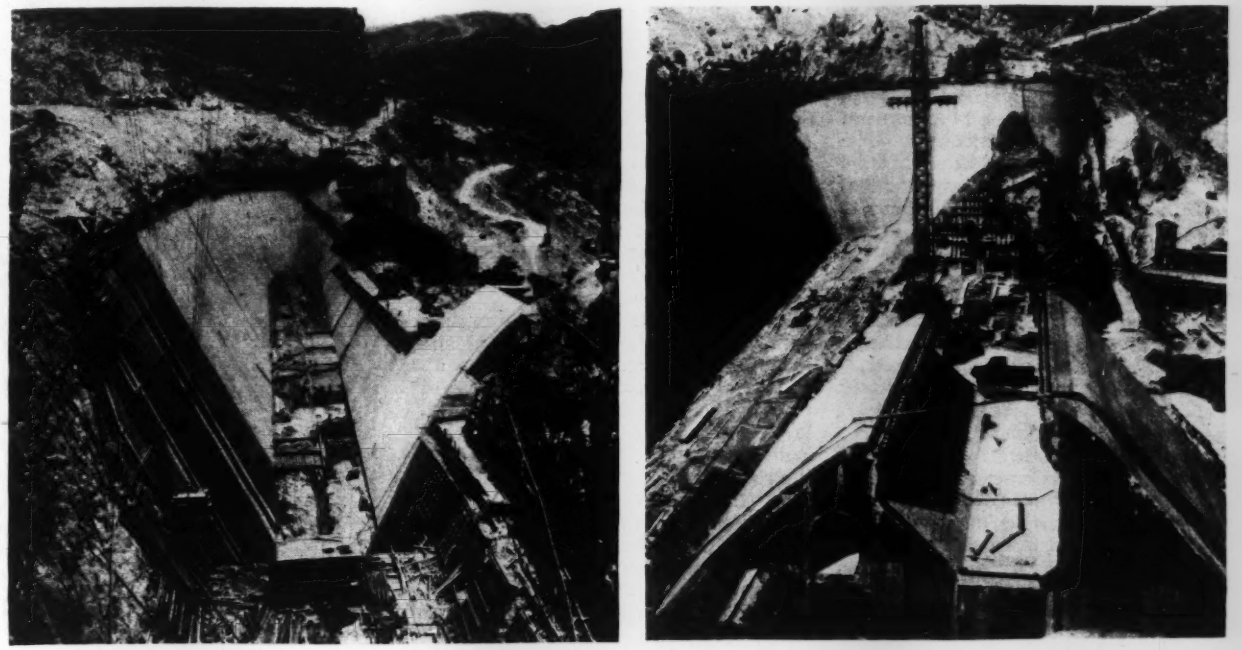


Fig. 1—General view of Nevada spillway (left) and weir crest and gate recess (right). Pier construction between the four 100-ft. gates has not been started. Lining operations with 4-yd. agitators handled by cableway are in progress (left). Total length is about 700 ft., and the lining on the back side, opposite the downstream gate, is 128 ft. from top to bottom.

has a uniform bottom width of 40 ft. At the upper end the depth is 75 ft., and the floor slopes on a 12 per cent grade to a depth of 128 ft. at a point opposite the lower end of the crest, depth being measured from the top of the channel lining.

The face of the weir that forms part of one side of the channel is a parabola tangent to a ½:1 slope; the lining forming the other side is laid on a similar slope. These slopes provide a width of 125 ft. (elevation of weir crest) at the upper end and 165 ft. at the lower end. From the downstream end of the last 100-ft. gate section a 55-ft. length of channel was added to improve hydraulic conditions and reduce the disturbance at the entrance to the transition leading to the inclined tunnel. At the lower end of this section of channel a step about 36 ft. high was introduced to provide increased depth, reducing the disturbance caused by cross-flow. A pipe provides for draining this sump, following flood discharge, into the main drainage manway. The crest of this step is the beginning of the parabolic curve forming the bottom of the transition leading to the 50-ft. inclined tunnel.

On the weir side the topography at each site necessitated the construction of a gravity dam of overflow profile that had a maximum height of 75 ft. on the Nevada side and 85 ft. on the Arizona side. Design and construction of these overflow weir sections were practically the same as for a dam of similar proportions. At quarter points on the crest of this overflow section are three piers dividing the crest into 100-ft. sections corresponding to the length of the steel drum gates. These piers are 11x27 ft. in section and are 36 ft. high.

Lining and Drainage—The sides and bottom of the spillway channel and transition are lined with a 24-in. thickness of concrete (18-in. minimum). The lining of the inclined shaft is 36 in. thick. Nominal reinforcement was used in the lining with the exception of the 50-ft. circular shaft, in which no reinforcement was used, and in the arched roof of the covered transition, which was very heavily reinforced. The channel lining was built in panels 14x15 ft. in plan dimensions, and each panel is secured to the rock by hooked 1¼-in. square bars grouted into holes drilled into the rock a minimum distance of 5 ft. These dowels anchor the slab and assisted in holding the reinforcing steel before concreting.

Because of the importance of these spillways, the volume of water to be handled and the high head on the lining an elaborate system of drains is pro-

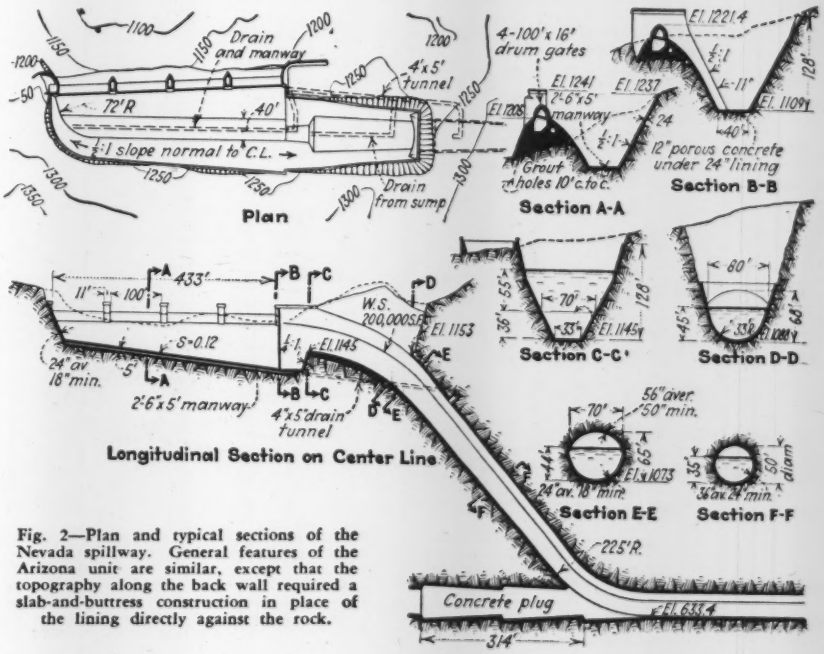


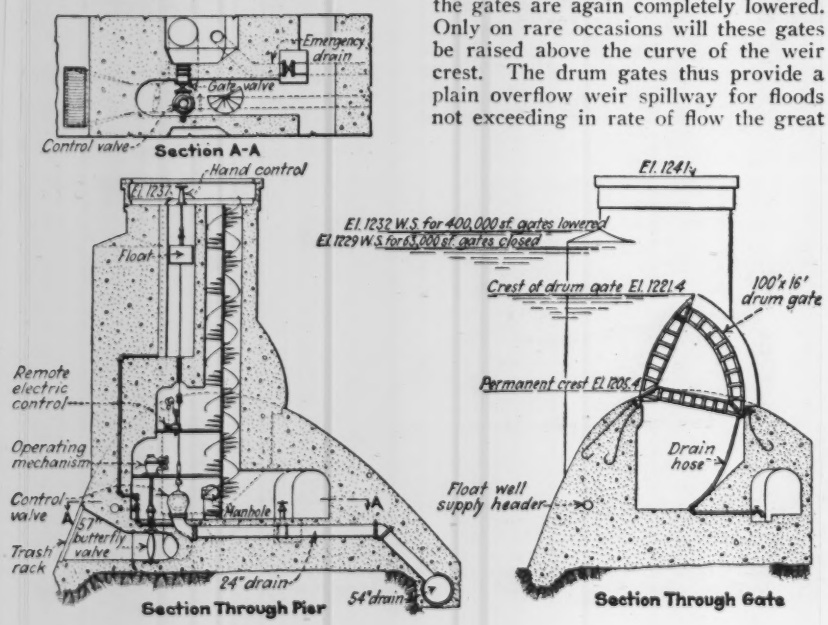
Fig. 2—Plan and typical sections of the Nevada spillway. General features of the Arizona unit are similar, except that the topography along the back wall required a slab-and-buttress construction in place of the lining directly against the rock.

vided. Running vertically under the construction joints in the lining are lines of porous concrete drain tile 6 in. square with a 3-in. hole in the center. This concrete tile is made of six parts of aggregate to one part of cement, tamped very dry into the forms. The result is a porous mixture that has the necessary strength and offers maximum space for drainage. The lines of tile extend down behind the joints to the bottom and across the floor to a 2½x5-ft. manway extending under the center of the channel floor. In addition to these drains, the whole channel bottom was underlaid with a minimum thickness of 12 in. of this same porous concrete.

The manway extends to the lower end of the channel, turns at right angles into a tunnel in the canyon wall, picks up the drainage outlets from under the weir structure and extends in a 4x5-ft. tunnel (concrete-lined), which turns at right angles to parallel the flow in the spillway and finally turns again at right angles to discharge into the top of the inclined tunnel 350 ft. below the end of the spillway (Fig. 2). This drainage tunnel discharges into the top of the inclined shaft (at capacity flow the shaft does not run full) to avoid disturbance of the hydraulic characteristics.

Gates—Each of the eight spillway gates (four for each spillway) is a bouyant structural-steel vessel 100 ft. long with flat bottom and two curved faces (Fig. 3). The resulting section resembles the conventional projection of a spherical triangle with each side about 17 ft. long. The gates are built up of structural-steel members, the outer surface of ½- and ⅝-in. plate being supported directly on built-up plate girders at 28-in. centers.

Fig. 3—Principal features of the drum gates and the operating arrangement.



In the lowered position the top side of the gates will provide a curved surface to complete the outline of the weir crest. Hinged at top and upstream side to the concrete weirs, these gates will float in recesses in the weir section (Fig. 1) and will operate to provide a maximum depth of 27 ft. over the fixed crest. The gates will be provided with spring seals at both ends and at the downstream lip to prevent leakage into or from the recess chambers. Possible leagage into the gates will be drained by flexible hose connections.

Automatic control (manual operation optional) provides for the raising and lowering of the gates in accordance with floodflow. When the water surface of the reservoir reaches a predetermined level, it enters the recess chambers and causes the gate to float up in advance of the rising water surface. When the gate has reached its maximum position pressure of the water against the bottom holds it in position until an additional rise in the reservoir, operating through the control mechanism, opens a valve and releases water from the recess chamber, allowing the gate to lower. This additional rise may be selected at will; in actual operation it is intended that the reservoir water surface will be about 7.5 ft. above the crest of the gate, corresponding to a discharge of about 63,000 sec.-ft. for both spillways.

The reservoir water surface will be maintained at this elevation until the gates are completely lowered. After this has occurred a rise of about 3 ft. in the water surface is required to discharge the designed capacity of 400,000 sec.-ft. At maximum discharge the head on the weir crest is about 27 ft. As the flood peak decreases, the gates automatically rise to their maximum position and then, as the water-surface level recedes still further, they fall again so that when the flood has passed the gates are again completely lowered. Only on rare occasions will these gates be raised above the curve of the weir crest. The drum gates thus provide a plain overflow weir spillway for floods not exceeding in rate of flow the great flood of 1884, and at the same time provide a huge reserve capacity.

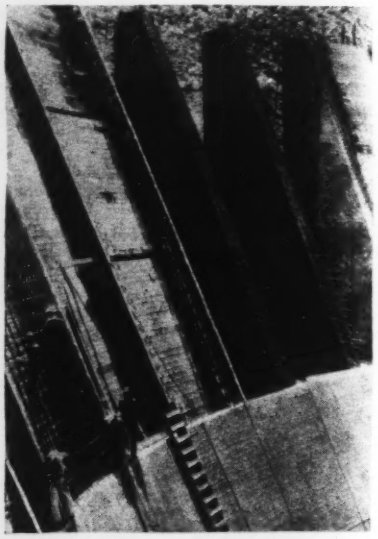


Fig. 4—Topography of the Arizona site required the back wall to be built as a slab-and-buttress dam. The view is the work at the curve at the upstream end.

Excavation—Removal of 600,000 cu.-yd. of solid rock by open-cut operations was required to provide for the two spillways. Drilling was done almost entirely by jack-hammers sinking downholes. The blasted rock was loaded by electric shovels into trucks for disposal. The removal of this yardage of rock outside the canyon area, as required by specifications, was the principal problem involved. Construction roads over steep grades with many sharp turns were necessary to make available side canyons at high elevations for the storage of this excavated material. On the Arizona side a large volume of this excavated rock was used as a fill to provide for the runway of a traveling cableway tower.

Concrete placing over such a large area provided a problem. Concrete from the high-level mixing plant was delivered in 4-yd. agitators on trucks and either moved directly by cableway to the pour behind the forms (Fig. 1) or transferred to 2-yd. buckets for more convenient handling. Forms consisted of timber panels, which were held in position by a separate system of rods doweled into the rock. The concrete paving on the floor of the spillway involved no unusual construction problem.

The Nevada spillway structure fitted well into the topography of the canyon, the back wall requiring only the concrete lining against solid rock. On the Arizona side the topography of the location did not conform so well with the required design of the spillway channel. This necessitated a slightly different design for the back side, which was carried up as a reinforced-concrete slab supported by buttresses (Fig. 4). With water in the spillway channel, this wall construction will act as a slab and buttress type of dam.

Progress on Small Tunnels and Intake Towers

Penstock tunnels driven and lining started—Bulkhead and stoney gates installed at diversion tunnel portals—Derricks and additional cableway will handle concrete for intake towers

CONCENTRATION on concrete production during the past six months has not delayed the prosecution of other features of the Boulder Dam project to keep them in step with the general accelerated program. In addition to the construction of the spillways (p. 590)—and the establishment of the penstock-fabricating plant and the start of this work (p. 751), the operations of the past months include the completion of the extensive program of tunnel-driving on the smaller penstock units, the start of lining these tunnels, including the Nevada inclined shaft from spillway to diversion tunnel, the installation of diversion tunnel gates and preparations for the building of the four intake towers. The general methods involved and the progress on these featured are briefly outlined.

Penstock tunnels

In addition to the four major diversion tunnels, the tunneling program on the project included: (1) One 37-ft. penstock header (30-ft. pipe) on each side of the canyon extending from the downstream intake towers for about 800 ft. to the location of four branches to the power house and then decreasing to a 25-ft.-diameter outlet header and terminating in six 11-ft.-diameter tunnels for 8½-ft. outlet pipe; (2) sixteen 18-ft. tunnels (13-ft. pipe), four from each penstock header tunnel, as just mentioned, and eight from the inner diversion tunnels; (3) two 50-ft.-diameter inclined shafts from the spillways to the outside diversion tunnels; and (4) four 26x43-ft. construction adits to provide access to the penstock header tunnels for installation of steel pipe. The location of these various units is shown in Fig. 1.

The largest units of this tunneling program are the 37-ft. inside diameter (41-ft. rough) penstocks which begin at the upstream end with a vertical curve from the base of the intake tower and divide into smaller branch tunnels at the lower end. This layout necessitated the construction adits both for tunnel-driving operations and the installation of the 30-ft.-diameter steel penstock header pipe. These tunnels were driven both ways from the adit with a rail-mounted jumbo, rebuilt from one of the pieces of equipment used in lining the diversion tunnels, mounting 30 drills. Each 14-ft. round required about 120 holes and took out all of the face except a 5-ft. depth of invert section. Mucking was done with a 2-yd. electric shovel loading into trucks (Fig. 2), which moved out to the portal of the adit and dumped the

Fig. 2—Muck in 37-ft. penstock tunnels is handled with electric shovels and trucks. These tunnels start at vertical curve from the bottom of intake towers and end in a group of small outlet tunnels. They were driven from adits.

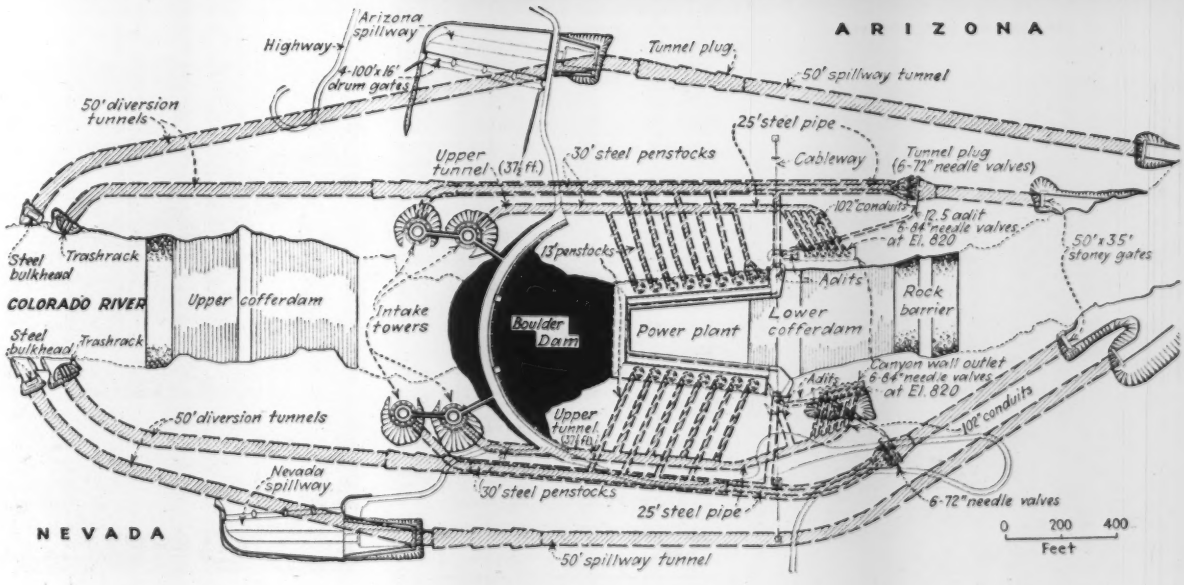


Fig. 1—Plan showing location and relation of various units of Boulder Dam project.

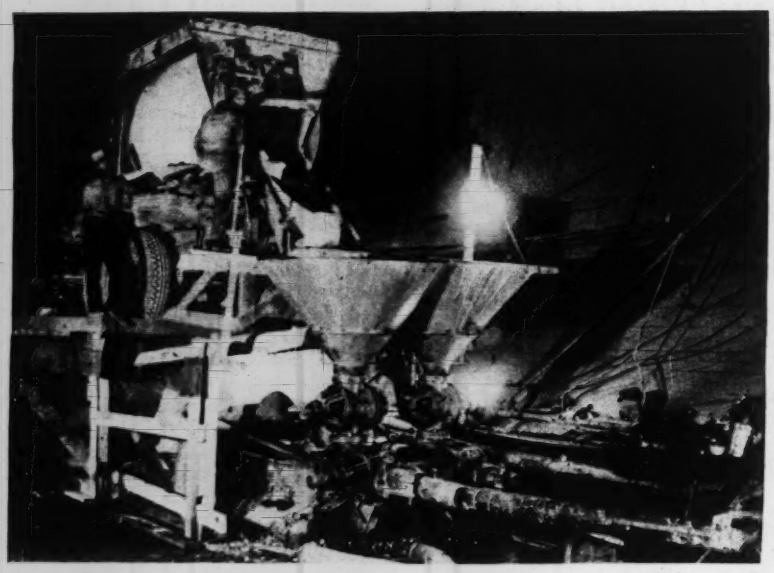


Fig. 3—The concrete pump is a new type of equipment in use at Boulder Dam. Rig shown here placed lining in riser shafts loading to canyon-wall outlets from inner diversion tunnels. Concrete for lining inclined penstock tunnels is now being pumped from lower portals.

excavated material into the canyon for removal. Ventilation was carried on with blowers and pipes and involved no particular problem.

The 2-ft. concrete lining has been started in both tunnels. A full-circle form is used, remodeled from one of the diversion-tunnel forms (Fig. 4). The form provides for pouring a 20-ft. section at one time and is mounted on steel needle beams for moving ahead after each pour. Concrete for this lining operation comes from the high-level mixing plant and is delivered by cableway to the portal of each construction adit. On the Nevada side the concrete transferred to trains is taken into the tunnel to the form and there dumped into the hopper of a conveyor-belt system, which discharges through a series of chutes into the sides of the form. The closing arch section is placed by pneumatic gun. This form was set up and started at the upper or intake tower end and will more down toward the construction adit.

On the Arizona side the lining form set-up is the same, but no tracks will be laid in the tunnel and trucks will be used to move concrete from the adit to the form. This different hauling arrangement has been intentionally provided to settle a question of the relative economy of rail transportation as compared to the use of trucks for this work.

The eight 18-ft. inside diameter penstock tunnels on each side divide into two groups, four descending on a slope of 33 to 46 deg. with the horizontal from the 37-ft. penstock header tunnels, and the other four alternating and extending horizontally from the inside diversion tunnel. These eight tunnels are 60 ft. apart and terminate on the canyon wall for the present, but ultimately will connect directly to the eight turbines in the power house. The drilling of the horizontal tunnels was done with a truck-mounted jumbo drilling a 14-ft. round for a full-circle section. The inclines to the upper penstock header tunnels were driven with a center heading on columns, followed by ring-drilling one round behind, with the muck dragged down to the portal by a slack-line cableway.

Mucking in the horizontal tunnels was done with a regulation mucking machine equipped with a lengthened conveyor belt discharging into trucks. All of this tunnel muck was discharged into the canyon for final removal. A 9-in. fan and a 12-in. blower pipe carried into the face provided ventilation. Truck engines were stopped during loading, and no trouble with gas was experienced.

Fig. 4—Belt conveyor carries concrete into steel-form section in lining sides and invert of the 37-ft. upper penstock headers. Arch lining is placed with pneumatic guns.

ORGANIZATION OF THE U. S. BUREAU OF RECLAMATION IN CHARGE OF BOULDER DAM CONSTRUCTION

Administrative:
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Executive office, Denver
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S. O. Harper, assistant chief engineer
J. L. Savage, chief designing engineer
W. H. Nalder, assistant chief designing engineer
L. N. McClellan, chief electrical engineer
B. W. Steele, designing engineer on dams
H. R. McBirney, designing engineer on canals
C. M. Day, mechanical engineer
E. B. Debler, hydraulic engineer
P. J. Preston, engineer in charge Colorado River investigations
Ivan E. Houk, engineer on technical studies
E. W. Lane, research engineer

Boulder City field office:
Walker R. Young, construction engineer
Ralph Lowry, field engineer
John C. Page, office engineer
G. L. Yetter, welding engineer

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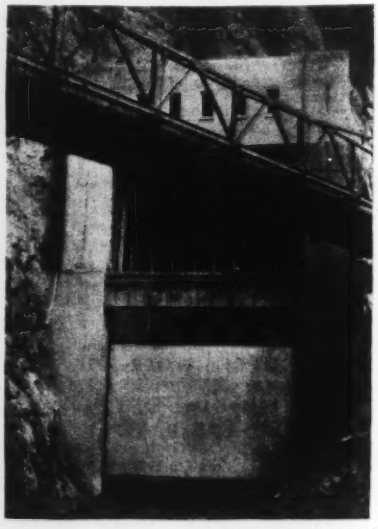
Bernard Williams, assistant general superintendent
T. M. Price, in charge of aggregate production
J. Perry Yates, office and designing engineer
B. W. Goodenough, field engineer

Fig. 5—Stoney gate on the downstream portal of the inside diversion tunnel on the Nevada side.



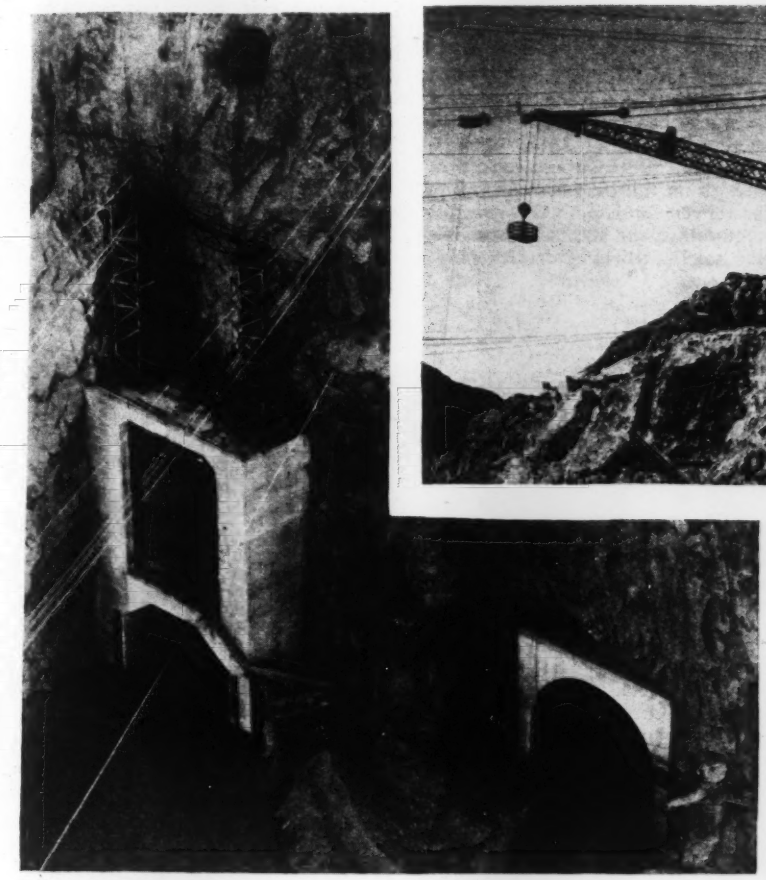


Fig. 6—Steel bulkhead gate in position at the upstream portal of the outside diversion tunnel on the Arizona side. This gate and a similar one on the other side will be lowered only once into final position to start storage in the reservoir. Low flow in the river permits a temporary cofferdam to make the other tunnel available for trucking.

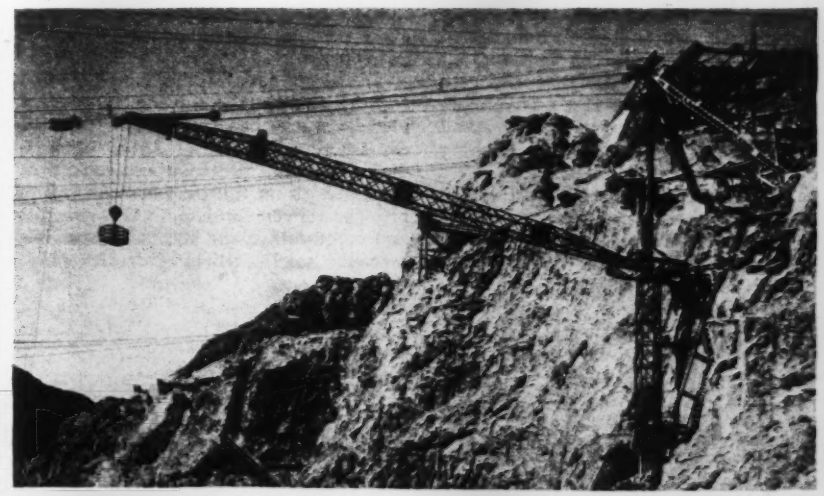


Fig. 7—Perched high on the canyon wall, this derrick is located above the site of the two intake towers on the Nevada side. It will be used to handle forms and concrete for the two towers. A similar derrick on the other side of the river will take care of the Arizona towers. A cableway will span between the two to transport concrete to the far side.

The 18-in. lining of these 18-ft. tunnels has now been started on the Nevada side, beginning with the inclined tunnels, as these must be completed first to permit proper sequence in placing the steel pipe sections, which probably will start in the 37-ft. Nevada penstock tunnels. To avoid interference with the operations inside the 37-ft. tunnel, this lining is being done from the downstream portal, using a concrete pump discharging into a full-circle timber form (Fig. 3), which is moved up the incline on steel needle beams as lining advances. It is planned to use this equipment against as high a head as possible and then complete the lining of these inclines from the upper end. The full-circle timber forms are moved ahead on steel needle beams.

The smallest tunnel units are the 8½-ft. horseshoe (excavated 13x13 ft.) outlets, six on a side, from the end of each penstock header to the canyon wall, which will discharge through 84-in. needle valves at gate houses. These tunnels are at El. 820, the same level as the 37-ft. penstocks, about 180 ft. above original riverbed. The outlets will be used to regulate streamflow and reservoir draft in conjunction with the discharge through the power plant. These tunnels average about 150 ft. long, are 27 ft. apart and are level. They were drilled from the portal end, using drills on bars. Nine-foot rounds advanced full-face headings. Excavation was handled by mucking machines loading into trucks that backed in and out of the tunnels dumping into the canyon. The trucks were a close fit in these small bores. After placing the 8½-ft. steel pipe sections, these tunnels will be backfilled with concrete.

Diversion tunnel gates

The two steel bulkhead gates at the upstream end of the two outside diversion tunnels and the two stoney gates at the downstream portals of the inside diversion tunnels have been installed and tested. The 50-ft.-diameter tunnels will be plugged at roughly midpoint after having served their primary purpose of river diversion; ultimately the two outer tunnels will be used for spillway outlets, and the inner pair will be used for penstocks.

After testing, the bulkhead gates (Fig. 6) will be lowered only once to begin storage in the reservoir. These 50x50-ft. gates are of heavy structural-steel construction designed to withstand the static head of 295 ft. (height to the intake tower discharge) and to close under a head of 60 ft. of water. The frame consists of horizontal cross-girders 55 ft. long and 12½ ft. wide, and the vertical members are 50½ ft. long by 10½ ft. wide. The skin plate of the gate is of steel 1¼ in. thick.

Erected in raised position, these gates are supported on I-beams, and at time of closure water will be introduced into hydraulic cylinders, the supports will be removed and the water released gradually to lower the gate into closed position. An elaborate system for securing tight closure is provided, including the use of cooling sprays to reduce the temperature of the gate to that of river water. In final position this gate is sealed with a rubber and bronze gasket. Each of these bulkhead gates weighs 2,180,000 lb., and the additional weight of the cylinders, wedges and steel frame is another 1,000,000 lb. The pair of gates, exclusive of the expense of erection, cost approximately $260,000.

The stoney gates on the lower end of the inside diversion tunnels (Fig. 5) are designed for raising and lowering operations under a balanced water head of 35 ft. and are for the purpose of shutting out backwater from the river below the power house to permit maintenance work on the penstocks. Each of these stoney gates is 50 ft. wide by 35 ft. high and consists of seven horizontal structural-steel girders 6 ft. deep at the center, connecting with vertical girders 3½ ft. deep on the sides and covered on the downstream face by a ⅜-in. steel plate. Two carbon-steel earplates extend above the upper edges of the vertical girders and connect with

the hoisting chains operating by sprocket drive through gears connected with a 10½-hp. motor. These operating chains, 83 ft. long, run from the gate round the hoist sprocket to a counterweight, consisting of a steel hanger and nine precast concrete blocks weighing 11,200 lb. each.

The suspended weight of each stoney gate and chain is about 260,000 lb., and the normal hoisting speed is 0.89 ft. per minute with a total lift of 58 ft. Cost of the two stoney gates complete, exclusive of erection, was about $64,000.

The deep cuts in the canyon walls for the four intake towers being completed, work has progressed toward construction of these 384-ft. shafts. To deliver concrete for these structures located high on the canyon wall and to provide convenient handling for forms and other equipment, the contractor has erected a steel stiff-legged derrick (Fig. 7) on each side of the canyon to handle a pair of towers. These derricks are located above the top of the towers, and the reach is sufficient to cover both. On the Nevada side the 180-ft. boom will reach to the track from the high-level plant to handle concrete. To transport concrete to the Arizona side and not interfere with operations on the dam, a cableway with fixed towers will be erected to deliver to the other derrick.

Record-Size Cableway Spans Black Canyon

FOR HANDLING penstock pipe and power-plant equipment during the construction period and for permanent maintenance work, the government has constructed a 150-ton cableway at Boulder Dam. This record-breaking installation (five times the capacity of any previously built) spans the canyon at the downstream end of the power houses and is on the line of the four construction adits driven to provide access to the penstock tunnels. The span between towers is 1,200 ft., and the vertical distance from the top loading platform to the lowest construction adit is 605 ft.

Since its completion several months ago, the cableway has been used by the dam contractor for miscellaneous operations (Fig. 1), but shortly after the first of the year installation of penstock pipes will begin.

Design and operating characteristics, as required by the specifications, were described in detail in *Engineering News-Record*, Oct. 6, 1932, p. 408, including a plan and profile of the installation. The special features of the final design and installation are outlined in the following:

Cables, anchors and other equipment

Cables—The track is composed of six 3½-in., 6x37, lang-lay parallel cables spaced on 18½-in. centers. Each of these cables is connected to anchor bars, and adjustment for equal tension is provided by means of hydraulically operated jacks actuating toggles between the socket of the cable and the anchor bar at the anchorage (Fig. 4). Each track cable has a breaking strength of 1,070,000 lb., making a total breaking strength of 3,210 tons for the six-part track. Under the design load of 150 tons the tension on the track cables will exert a 2,000,000-lb. pull on each anchorage.

The hoist cables and endless rope are of 1⅛-in. diameter and operate from the carriage to hoisting drums for moving the load along the track and for lowering and hoisting. These ropes are supported at 100-ft. intervals by carriers attached to the main carriage (Fig. 3).

Anchors—Excellent rock at both ends of the cableway made feasible a mushroom type of anchor consisting of a 60-ft. length of 7x9-ft. tunnel opening into an 18x18x10-ft. chamber. After anchor steel had been installed in this opening, the chamber and tunnel were backfilled with concrete to a depth of about 50 ft. On the Nevada side there is a 90-ft. structural-steel tower supporting the cast-steel saddle curved for proper contact. On the Arizona side no tower was required, and the clear span starts at the concrete saddle.

Operating Equipment — The hoist house containing all the operating machinery is located on the Nevada side of the canyon between the anchorage and head tower. Each of the two main-hoist drums is 13 ft. in diameter and 17 ft. long, providing sufficient area to wind the hoist rope in a single layer. These drums are grooved for each turn of cable. A special feature of the drum construction is the use of structural-steel members with welded connections, as shown in Fig. 2.

Each of these drums is operated by a 125-hp. d.c. motor through a geared

Fig. 1—Everything moves by cableway in the dam-site area. The government 150-ton cableway, by far the largest ever built, is doing odd jobs, such as lowering trucks to the bottom of the gorge, until it is needed for its main task of handling penstock pipe and power-house units. Temporary hoist line shown here will be replaced by 16-part line before any real lifting is done. Steel cement silos in the background are part of high-level mixing plant.

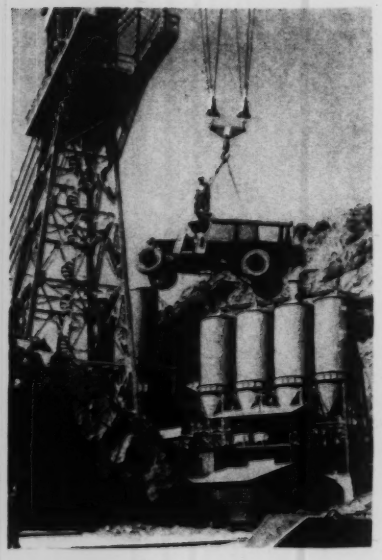
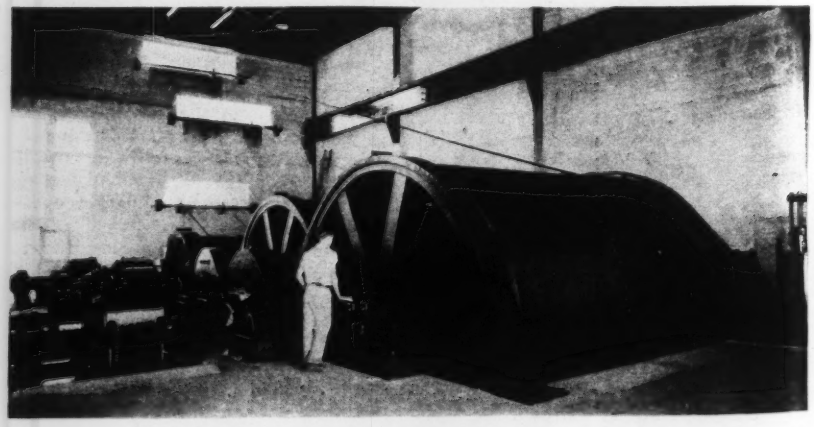


Fig. 2—Two main-hoist drums are 13 ft. in diameter and 17 ft. long, equipped with solenoid brakes. Conveying line drum can be seen next to far wall. Note welded structural-steel construction of drum spokes.



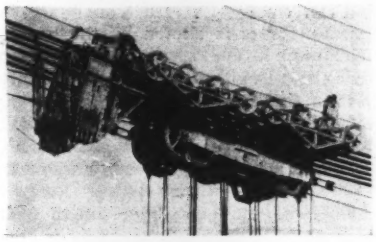


Fig. 3—The carriage rides the six-track cables on 48 wheels. Besides the track wheels there are enough line sheaves in this rig to provide a 16-part 1⅛-in. line for hoisting 150-ton loads.

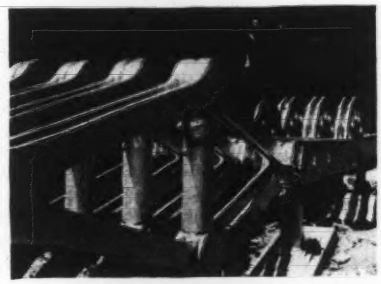


Fig. 4—Hydraulic jacks within adjustable toggles provide for equalizing the sag of the six track cables. This installation is at the Nevada anchorage.

speed reducer. The two drums and their separate motors are synchronized by an electric control mechanism to provide equalized hoisting at all speeds. From these hoisting drums the 1⅛-in. ropes are reeved in sixteen parts on the line supporting the fall blocks. Operating speed for the hoist is 120 ft. per minute for small loads and 30 ft. per minute for the maximum 150-ton design load. In addition, there will be two inching speeds for picking and spotting heavy loads, which provide a minimum movement of 5 ft. per minute.

A separate drum for the conveying line, 8 ft. in diameter and 10½ ft. long, is driven by a 400-hp. d.c. motor operating through a herringbone gear reducer. This drum carries the two 1⅛-in. ropes for movement of the carriage along the track. The speed of the carriage is 240 ft. per minute, with additional provisions for creeping speeds on approaching any station.

The hoisting equipment is provided with service and emergency brakes designed to decelerate and sustain full load under all operating conditions, including the interruption of power service. Under normal deceleration of load, dynamic breaking is provided before using the service brakes, but the latter will function automatically in case the dynamic breaking fails. The service brakes are of the solenoid-operated type. In addition to these brakes, there is an emergency brake for each drum held normally in released position and also capable of decelerating and holding the maximum load in any emergency.

Control—Operation of the cableway is by remote control either from the main control station, which is supported on cantilever I-beams over the canyon, with a view of all loading platforms, or by interlocking change-over switch to any of the other four stations at the loading platforms. In the main control house there is a permanent installation, and the equipment at the other control stations will be of the portable type. Interlocking is provided in changing the control from various stations, and any loss of power provides for automatic setting of brakes.

Organization—The cableway was designed in the Denver office of the U. S. Bureau of Reclamation under the general direction of R. F. Walter, chief engineer. The contract for furnishing and erecting the cableway equipment was carried out by the Lidgerwood Manufacturing Co., Elizabeth, N. J. The government, under separate contract with the Six Companies Inc., provided the excavation for anchors, hoist house and tower, in addition to the concrete for this feature. The Lidgerwood Co. also contracted with the Six Companies Inc. for erection of the cableway.

Gorge Excavation Confirms Geological Assumptions

Original advice on geological features of Black Canyon checked by subsequent investigations—Removal of river fill reveals tight and sound canyon floor ideal for foundation of dam—Evidence points to movement of entire river sediment during floods

FIVE YEARS AGO a board of engineers and geologists, reporting on the feasibility of constructing a huge dam on the Colorado River, recommended the Black Canyon site as the most favorable (*ENR*, Dec. 13, 1928, p. 887). As the dam under consideration was to be by far the greatest ever built, proper selection of a site was one of the most important engineering problems involved in the whole project. At that time the canyon walls were formidable, defying intimate inspection. The gorge floor, upon which millions of yards of concrete were to be safely carried to impound millions of acre-feet of water, was buried far below swirling muddy waters and an unknown depth of river sediment. Six months ago that canyon floor was artificially scraped clean, revealing geological formations for open inspection.

Every major contention and assumption made by the board five years ago regarding the geology of Black Canyon as adapted to the site of the dam has been confirmed by intimate examination of the gorge in the dry. The rock formation is thoroughly capable of bearing the load and resisting the thrusts of the dam. Watertightness of the walls and floor is beyond all expectations. Preparation of the foundations required little more than removal of overlying sediment. Professor Charles P. Berkey, a member of the original board, has submitted an official report of the geological features of the site to the Bureau of Reclamation, following a personal inspection of the excavated river gorge. This report, made May 31, 1933, is abstracted in the following.

On the whole, the results of all the later work connected with the structure confirm the essential accuracy of the original statement of the Colorado River Board with respect to the good quality and the excellent working behavior of the rock forming the canyon walls, the tight character and favorable behavior of the river fill, the soundness of the floor of the gorge and the general physical feasibility of the undertaking so far as geological factors were concerned. If the items covered in the first report of that board were written now with all of the advantages of subsequent construction experience and full exposure of the site, none of them would require material modifications to fit the actual facts as found. In no case have new or unexpected conditions introduced geologic surprises of sufficiently serious character to require change of plan or design, marked revision of estimate or method of handling of the main structure.

Major geologic features

Character of the Abutment Rock — The canyon walls at the side of the dam were judged to be essentially sound before the abutments were cleaned and excavated to the desired form, but actual excavation, bringing into close observation and review every foot of the bearing surface, leaves nothing to conjecture. The rock is sound and reasonably uniform and unusually free from objectionable or large weaknesses. Such fractures, joints and variations of quality as exist are distributed in heterogeneous manner and do not establish continued lines of weakness and consequently can

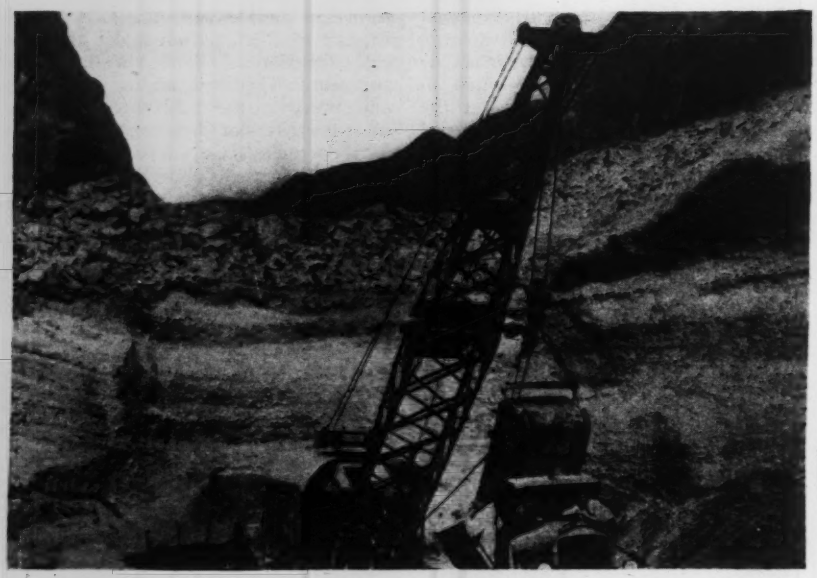


Fig. 1—River fill at dam site proved to be compact, tight and remarkably stable, providing ideal foundation for cofferdams. Stratification of sand and gravel layers is well illustrated by this view. Broken rock on top of fill is from canyon-wall scaling.

be easily covered or bridged over. Even the major joints and slips are for the most part tight, and many of them are rehealed. Such of them as do open can be grouted without unusual difficulty. The abutments under development, therefore, have proved to be exceptional in every respect.

The Rock Floor—Now that the rock floor is uncovered it is possible to check in detail the points that could only be estimated heretofore. There is no doubt but that the foundation as a whole is sound. The gorge does not follow a fault zone, and the rock of the floor is similar in all essential respects to that of the lower canyon wall. Wherever it is more jointed than elsewhere, the stream has eroded deeper. There is also an inner gorge, marked by a deep pot-hole erosion, forming a narrow and somewhat tortuous channel along the center line at a depth of 75 to 80 ft. below the rock benches on either side. In places the outer lips of the rock terraces are pitted profusely with shallow pot-holes, but for the most part the side benches are comparatively smooth and surprisingly flat and uniform. In striking contrast the inner gorge is deeply pitted and fluted along the side walls and is markedly uneven in form and depth (Fig. 3). The average depth is about 75 ft. below bench level. Both the bench and inner gorge vary in prominence with the quality of the rock. Wherever the rock is crossed by a crush zone or is considerably jointed, there erosion has cut most or all of the bench away. In consequence, there are notches in the bench reaching in favorable places almost or quite to the main canyon wall.

Fig. 2—Finding of a sawed plank on rock bench at top of inner gorge, buried deep in undisturbed river fill, gave conclusive proof of great depth of scour in recent times.

It is especially satisfactory, therefore, to note that at the precise site of the dam the bench has better form, is higher and wider, and is less cut up by erosion depressions than it is immediately above or below. Furthermore, it appears that nowhere else within the range of exploratory study have so many additional advantageous features been found. Evidently the dam has been located at the right place. If the floor had been stripped as it is now, before the exact site was selected, it could not have been located more accurately to take advantage of the best local physical conditions.

Special Erosion Features — Pot-hole erosion is of itself no unusual phenomenon. It is in fact a common formation of erosion in a rapid stream flowing over fairly uniform massive rock. The more striking feature is the bench form at either side with its abrupt change of profile, both at the inner and outer margin. This bench or terrace form is a fairly constant feature of the canyon bottom, for it is shown by the borings on almost every section line, both in Black and Boulder canyons. The sharpness of the form, however, was not disclosed until the floor was uncovered. This clearness of form seems to mean that the mass of sediment across the whole gorge actually moves in great flood tides, subjecting the entire width of floor to scour, while in addition there is a concentration of whirling movement in the center that sets up pot-hole erosion to a greater depth.

The assumption that the whole mass of river fill has moved in present times seems at first difficult to believe and was doubted by most observers. That question, however, is virtually settled now by two observations: first, the essential continuity and similarity in quality and condition of the river fill from top to bottom; and second, the finding of a sawed plank of lumber lying under the gravel on the edge of the inner gorge, a place that it could not have reached in any imaginable way except by burial during some comparatively recent flood (Fig. 2).

The river fill

The sand-gravel-boulder mass filling the bottom of the gorge to a depth of approximately 120 ft. has been from the beginning a feature of considerable uncertainty and difference of opinion. There was no way of telling from the borings or any other source whether or not it would stand up well against excavation or whether instead it might slump and ravel badly when exposed. Neither could it be definitely ascertained whether much or little water would be furnished through it into the major excavation. It was rather commonly believed that the lower portion of the mass was not moved in present-day floods and might be much older and more compacted than the upper portion, which of course is known to be affected by modern scour and fill. It has been an agreeable discovery on completing the excavation to find that the whole stratified mass is essentially tight, furnishing surprisingly little water in this immense excavation; that it is also unusually stable, standing up well in almost vertical walls 10 to 30 ft. high, and that, despite this behavior, it is virtually uncemented from top to bottom, permitting easy excavation without special loosening (Fig. 1). With such behavior it is clear that the cofferdams that rest on this river fill are safe as far as these foundations are concerned, and that special trouble from this source need not be feared even in flood time.

The Spillway Breccia—Over a small area in the vicinity of the spillway on the Arizona side the local rock exhibits a decidedly more porous condition and a more varied volcanic fragmental make-up than elsewhere on the dam site. There are many very large blocks included in the cumulative mass and a

great variety of igneous rock types. Sedimentation structures in this mass are either lacking entirely or are obscure and patchy in distribution. Furthermore, the fragments composing the rock present extremely varied physical conditions because of the vigorous chemical attack on the mass subsequent to its accumulation. The most reasonable explanation of this formation is that the mass of rock in the vicinity of the Arizona spillway represents an accumulation in and over one of the local volcanic vents of that time. Even after the accumulation was made, volcanic gases continued to escape through the loosely fitted mass of mixed material until these forces died down. There is nothing extraordinary about the occurrence. There is no reason to expect special difficulty or troublesome behavior. The mass is amply strong to support the structure designed for it and sufficiently stable to serve its purpose. It is not as tight as the average of this formation, but its porosity is no great detriment to its proposed service.

Minor features

Hot Springs—At several places within the walls of the inner gorge, warm water issues from crevices in the rock. Temperatures of 88 deg. F. and 99½ deg. F. were found at two points just above the upstream toe of the dam at a time when the river water had a temperature of 62½ deg. F. Much smaller amounts of water issue from other streams at several places along the inner gorge walls, but none of these appears to have abnormal temperatures. These springs can be handled by blocking off, building up ahead of course, but some other outlet would surely be found either above or below the dam in a roundabout manner through the related joints of the foundation and the abutment rock, and no anxiety need be entertained on that point. In case the waters are found injurious to concrete, they can be drained away from the dam.

Slabby Rock — At numerous places along the lower side of the gorge the rock exhibits a peculiarly regular slablike cleavage. These slabs or plates are not very regular in form, but they do give the rock a prominent structural appearance that suggests some special cause. Examination shows that the physical make-up and original bedding structure of the rock has virtually nothing to do with the slabbing formation. The plates are as likely to cut across the structure as to follow it. It is possible that weathering has been the cause of this formation, but this is not very convincing, for there are many places equally as exposed which do not show the effect at all. It is possible that the rock has been suppressed to a more critical internal condition than the average at these places, so that when the force is removed it tends to expand and rupture. In this manner it might develop a sort of crude cleavage, as sometimes happens with the so-called "popping rock" of deep tunnels. According to this view, the river gorge is a great channel cut down deep into the somewhat unevenly crowded and strained rock, some portions of which in the course of a long time and with the help of weather, have registered readjustment by splitting up in this peculiar manner. Removal of loose slabs from the floor wherever they exist is recommended.

Mud Seams and Fault Zones—An occasional joint in the bottom of the gorge has enough spread to allow mud to collect in it. There is nothing unusual about this, but the fact that the walls do not fit tight together and also that the filling substance is soft clay, which would interfere with grouting, raise a question of treatment for support of such a great structure as this dam. The rocks involved are sound enough. The occurrence of mud seams does not indicate decay or excessive weakness. It is essentially a superficial feature, probably due to the pressure phenomena already discussed. Joints reaching the surface and standing at steep angles will be bridged over by the dam. Where the mud seams lie flat, the overlying rock can be excavated to solid material without much trouble.

Fig. 3—Erosion of deep inner gorge produced walls of characteristic fluted structure.

Although there is no major fault in the site or in the immediate vicinity, there are many small displacements and slips of secondary and very minor significance in the canyon wall. There is no evidence of recent movement along any of these lines, and although there is no likelihood that water circulation of consequence could be established along any one of them, it is advisable to provide for grouting of the extension of one of these on the Arizona side, the course of which carries it behind the abutment on that side. No other places seem to invite such treatment. This is because they were tighter to begin with, or farther removed from the dam and therefore out of range.

Summary

The foundations and surrounding features of the excavation of Boulder Dam are reassuring in every important particular. The rock of the floor is as good as that of the canyon wall. There is no major fault or other weakness at the present time along the bottom channel. The erosion phenomena are normal, and the forms produced are those belonging to rapid streams. The river fill is surprisingly tight and stands well, thus insuring safe support of the cofferdams. There is little water to handle from the excavation. There is not the slightest doubt about the general stability of the foundation and abutment rock. As far as the physical features and conditions are concerned, the site has developed more favorably than was predicted for it.

No surprises have been disclosed. Although most of the ground has turned out to be sound and uniform and has behaved exceptionally well under construction, the Arizona spillway has encountered more porous and somewhat weaker rock than any other section of the work. Fortunately, it is not sufficiently unstable to require any important change of plan, although special care in handling this section is being taken.

Although there are many soft spots in the rock, marked chiefly by individual constituent fragments that have been altered since the rock was placed, there are no continuous weaknesses and little or no soluble or easily destroyed material. This condition does not introduce any complications, for all such minor weaknesses are bridged over, making the average quality only of practical significance. The rock of the foundation does not soften materially under submergence and, although moderately porous, it is virtually impervious. There is some jointing, and such water circulation as there is follows these structures. They are neither very numerous nor very open, and they tend to tighten with depth, but their existence makes a program of grouting necessary.

The rock floor is sound and fully competent to carry the load contemplated, with only the usual precautions in providing a good bearing surface and making provision for grouting. The abutments are similar to the floor in character of rock and structural quality, and they require similar treatment. Any belt of more numerous joints than usual and any crushed stone coming close to the dam should receive special attention in grouting to check effectively the water seepage.

The sum total of evidence available from construction supports the original opinion that this site is one of the best on the river, that its physical support and surroundings are excellent, and that perfect operating behavior is to be expected when the work is completed.

Engineering News-Record

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To Measure Building Needs

BY EXPANSION of the real property survey plan initiated at Cleveland to a number of other cities through the medium of CWA funds, a highly important advance in knowledge of building history and needs is in prospect. The survey will give the first tangible measure of some major factors controlling city developments and capital investment. It will afford a guide to efficient city planning and the construction of buildings and improvements by giving data on rate of obsolescence of individual properties and city districts as a whole, and variation of producing power of property, stability of use and population—all of these being facts needed by both private and public agencies for intelligent planning. Investment in these surveys is one of the most constructive applications of CWA funds that could be made, since in addition to creating a dollar's worth of employment for every dollar spent it lays a solid foundation for new values.

Funds Misapplied

ALLOCATION of $500,000 of the Recovery Act fund to the Federal Alcohol Control Board by the Public Works Administration is an application of money from that fund to a use for which no justification can be found under the Recovery Act. It marks the climax of a series of questionable extractions from the fund that began when $400,000 was taken to finance a power-development study by the Federal Power Commission. This diversion of funds now includes $301,000,000 to the Civilian Conservation Corps for "anticipated expenses" and $20,000,000 to the same organization for land purchase, $2,000,000 to the Department of Agriculture for plant-disease control and $10,000,000 to the Interior Department for soil-erosion control, all of them undertakings not contemplated by Congress when the act was passed. The act was directed toward making up the lag in public construction, and as its $3,300,000,000 fund is not adequate to finance even this specific class of work, it should not be depleted by diversions for enterprises not authorized by Congress, worth-while though they may be.

Useful Investment

ENCOURAGING contrast with the diversion of PWA funds to administrative use is afforded by some notable PWA allocations of the past week or two, which combine re-employment with urgently needed public service. The funds allocated to completion of the New York subway system and the sewage-treatment works of the Chicago Sanitary District both have immediate value. The former will create an extensive transportation system of which only the main trunk now exists, and thereby will increase the efficiency of the city, facilitate business, and bring nearer solution the unfortunate tangle of rapid-transit operation. For the Chicago Sanitary District the new loan brings measurably nearer reality the complete treatment system on which the welfare of a great community depends. Neither of these two enterprises, moreover, is in any manner competitive with existing business.

In New Dimensions

SUCCESS in landing the first deep caisson of the San Francisco Bay Bridge directs attention once more to the way in which great construction undertakings of the present time are going into new dimensions in their foundation work. The New Orleans Bridge, as well as the San Francisco Bay crossing, the Atchafalaya River Bridge at Morgan City and the projected Baton Rouge Bridge all require depths of foundations that would have been considered almost impracticable but a few years back. Deep piers for these bridges are possible not so much because of major engineering developments or more ample funds as through increased technical skill. An instance is the solution of the Bay Bridge problem, involving foundations 226 ft. deep, by floating the caissons with special air chambers formed by closing the tops of the dredging wells. Another instance occurs on the New Orleans Bridge, where cellular concrete caissons are to be used in which all walls, exterior and interior, are equipped with closely spaced vertical tubes giving access to the cutting edges at a maximum depth of 180 ft., for jetting, drilling or cutting away obstructions; these caissons will be open-dredged through artificial sand islands such as were first used on the Suisun Bay railway bridge in California. In such developments of methods to solve new problems it is made evident that present-day engineers bring to their work a full measure of resourcefulness and skill.

A Check on Incompetence

ALMOST as significant and radical as the Tennessee Valley Authority's recent announcement of a broad policy of public power control is one detail of the TVA's first power-sale contract that has quite general bearing on public service administration. Under the power contract made with the city of Tupelo, Miss., the city is required to segregate its power accounts and funds from all its other accounts. Such segregation is what advocates of sound municipal government have long urged for all revenue services of cities, particularly water. Segregation of accounts is so rare as to be all but non-existent, and segregation of funds is even rarer. Municipal officials too frequently object to segregated accounting because it would show how rates are related to cost of service; they object to segregation of funds because it would prevent the fudging and transfers that are too commonly resorted to in order to conceal inefficient operation and bad budgeting. Unfortunately the charge of mental dishonesty extends beyond the public officials to the citizens, for they show time and again their eagerness to finance general expenditures from the income of public services and oppose the determination of rates on a proper cost basis. The determination of the TVA to enforce a sound principle of service-cost determination and charging will be a check to such incompetent procedure in power service, and in time should help to bring about sound practice in public-service operation generally.

Estimating the Shortage

VALUABLE DATA were compiled recently by the governmental study group that carried out the analysis of construction requirements and possibilities abstracted in our last issue (p. 715). The amount of required construction during 1934 and 1935 exceeds thirteen billion dollars, or nearly seven billions per year. This is so near the country's normal rate of construction to meet the current demand as to indicate that the suggested program would fill one of the largest remainings gaps in employment and business activity and by so doing would make a decisive contribution to recovery. It may be that the investigators set about their study for the very purpose of devising a plan of normalization; but the fact remains that their estimate reflects quite faithfully the actual construction deficit. The magnitude of this deficit is a fact of great public moment.

During the decade 1920-'30 the country's annual construction bill averaged about seven and one-half billions. Roughly speaking, one-third of the money went for housing, one-third for industrial and commercial requirements and one-third for public works. Since 1929 a deficit has been accumulating, at first slowly but with 1931 at rapidly increasing rate. It now exceeds twelve billions, and probably approaches fifteen billions. The deficit is certain to be made up, but while it remains it represents the biggest single factor in continuing the depression, as it accounts for the loss of at least ten million man-years of employment, with all that this means in impoverishment, distress and reaction on industry. It also constitutes the most serious threat to stability after the depression is overcome, for by throwing an abnormal volume of building activity on top of regular business it would inflate prices and values and accelerate consequent collapse.

Some elements of the deficit are worth considering. New housing is required each year for 750,000 to 1,000,000 families, to meet the losses of fire, decay and obsolescence and to provide for normal growth. Temporarily this demand is elastic, depending on the individual pocketbook, but in the long run it is stable and real. The housing deficit represents several years' accumulation of this demand. The deficit in municipal public services such as water supply, waste disposal, and other service facilities exceeds the value of two billion dollars. Bad pavement and mud roads represent a like deficit. Interrupted grade-crossing elimination and improvement of neglected or obsolete railway equipment and port facilities also represent billions. In manufacturing plants and commercial buildings there are shortages of vast size that have accumulated in spite of the much discussed overbuilding.

The sum of these elements, however, represents only the deficiency that has been incurred during the depression as compared with the normal rate of meeting construction requirements. In addition, there are huge deficiencies in inadequate facilities whose improvement has never been approached. Thus the survey already mentioned cites the fact that even in the active year 1929 more than a million family accommodations were so far below a reasonable living standard as to require replacement. The fact is that construction has at no time been more than an answer to current demand. Even in the years of largest construction volume, when the total of operations in the United States reached a value of more than ten billion dollars, improvement and replacement were doing no more than keep pace with the country's growing needs, and there was no net gain on past deficiencies. We may conclude, therefore, that until this rate is again approximated the standards of living are being progressively lowered, and that the deficit must soon be made up if we are not to continue on a permanently lowered plane.

Wage Rates for Engineers

MUCH misunderstanding exists in relation to the matter of wages for employed engineers and engineering assistants under the engineers' code, and no small amount of criticism has been directed toward the code committee for its failure to write into the code a minimum wage that even approached an adequate minimum for men of engineering training. Many have said that the figure now in the code—the 40c. an hour of the basic construction code—is a minimum wage for engineers and as such is absurd even for sections of the country where living costs are low.

The wage provisions of the code are clear: first, a minimum wage for the lowest grade of worker likely to be employed by an engineer, such as an axeman; and, second, a provision that minimum wages for the technically trained employees, engineers and engineering assistants, shall be set regionally by a subcommittee within three months after the approval of the code. With this definite provision for setting minimum wages for engineers and engineering assistants, it seems obvious that the minimum in the code is *not* intended to apply to these two classes of technical men.

Postponement of the setting of rates for these two classes until three months after the approval of the code frequently has been declared unnecessary and undesirable. It is stated that it should have been possible to set rates for several classifications of both engineers and engineering assistants in the months that have elapsed since the code work started. In retrospect, that is true, but when the postponement provision first was written into the code last summer it was thought that the code would be approved in a few weeks. Since then approval always has appeared to be just around the corner. That, as well as the fact that the code committee continually has had to adjust its thinking to changing NRA requirements, has kept the committee from doing many things that otherwise might have been done.

Now a new development within the NRA indicates that had such action been taken it would have been wasted effort. Except in industries in which both employers and employees are almost fully organized, the NRA will approve no rates in a code other than one basic minimum. In the code for materials inspection, for example, where two rates for technical employees were prescribed in addition to the basic minimum, both were cut out when the code, after a public hearing, was submitted to the NRA for review.

On the other hand, the obligation to establish adequate regional rates stands as the most important action to be taken after the code is approved. There is increasing evidence of a feeling among engineering employees that the code committee has been lukewarm toward the pay issue and that its members, with the employing engineer's interest in mind, have sought to prevent any increase in service cost to the employer. If this unfortunate opinion is to be controverted, there must be prompt action by the code committee on the subject of regional wage rates as soon as it is known what procedure the code will permit. Adequate rates must be established quickly.

NEWS OF THE WEEK

President to Ask Funds to Continue Civil Works Program

PRESIDENT Roosevelt's plans for carrying forward the Public Works program next year will not be presented in their entirety when Congress convenes Jan. 3. A comparatively small appropriation to replenish the public works fund will be recommended but the President is impressed by the desirability of studying the social aspect of public works, apart from political and economic factors, before committing himself to any new program of considerable extent.

With 4,000,000 men now on Civil Works payrolls, President Roosevelt is expected to ask Congress for an appropriation of about $350,000,000 to supplement the initial allotment of $400,000,000 from the public works fund. It is estimated that this will carry the full complement of 4,000,000 men through to March 1, with a rapid reduction by climatic zones in CWA crews following that date, in the hope that all may be discharged from the rolls by April 15 or May 1, as the public works program gets under way and more opportunity for private employment presents itself. In direct conflict with this program is the proposal of the U. S. Conference of Mayors to increase Civil Works payrolls to 8,000,000 men.

Civil Works rates fixed

Regulations issued by the Civil Works Administration fix minimum salary scales for "white collar" employees under which men with no previous training will earn at least $15 a week and those whose work necessitates "a recognized expertness or skill gained by specific training or experience" will get a minimum of $18. Supervisors over groups of workers are assured of $21 a week and technical supervisors may be paid as much as $40. White collar employees may work 30 hours a week, although all others are limited to 30. Wage rates paid to classifications intermediate to the PWA rates for common and skilled labor, such as apprentices and helpers, must reflect the prevailing differentials in their communities. CWA has adopted the same provision as PWA for hiring union labor through recognized locals. If such requests are not filled by the local unions within 48 hours, workers may be drawn direct from the lists of the U. S. Employment Service.

New Railroad Line Proposed

The Missouri-Kansas Belt Railway & Terminal Co. has applied to the Interstate Commerce Commission for permission to construct a railway line from Kansas City, Mo. to Valley Falls, Kansas, with branches from Leavenworth to McLuth, and from Oskaloosa to Topeka, a total distance of 115 miles. The company is a new organization.

Contracts Let for Large Map of U. S. Indian Reservations

Acting in behalf of the Soil Erosion Service of the Department of the Interior, Secretary Ickes has awarded to the Fairchild Aerial Survey, Inc., a contract for making the largest single aerial photographic mosaic map ever undertaken. The map will cover 24,500 sq. miles of land in the Navajo and Zuni Indian reservation in the states of Arizona, New Mexico and Utah. The map will be at a scale of 1 in. = 2,300 ft. and will be about 40x24 ft. in size. Photographs will be taken from an altitude of 2,000 ft. and about 4,500 photographs will be required.

At present there are no accurate maps of the greater part of the Navajo reservation. The total cost of the aerial survey will be about $77,000 as compared with a ground survey estimated to cost $500,000.

Construction Industry Code Nears Approval by Johnson

As this issue goes to press the construction code has been agreed on in respect to all major differences and is reported to be likely to go to Hugh S. Johnson, Administrator, on Thursday, Dec. 21, with half a dozen or more of its major divisions. In view of the extensive discussions through which the code has gone, prompt approval is expected.

In its final form the code is a single document embracing the construction industry as a whole and its individual components. Chapter I covers the definition, labor conditions, administration and trade practices of the construction industry, while following chapters cover more specifically the several component industries. With Chapter I the following division chapters are expected to go through at present: General contractors, painters and decorators, elevator builders, mason contractors, heating and piping contractors, tile and mantel setters, plumbers. One or two other divisions may be ready for action at the same time. The engineers and architects divisions continue under discussion, mainly on the point of whether minimum fees are to be written into the code.

New Railroad Station Opened

The new station of the Pennsylvania Railroad in Philadelphia at 30th St. on the west bank of Schuylkill River was put into service on Dec. 15. It is designed to replace the Old Broad St. station and to permit the elimination of the elevated approach to that station known as the "Chinese Wall." For a year or more a new underground suburban station near the Broad St. station has been in operation and the suburban section of the new main station on the west bank of the Schuylkill River has been used for part of the through train service to facilitate completion of the main station.

Highway Bridge at Baton Rouge Gets PWA Loan

A LOAN and grant totaling $7,000,000 to the state of Louisiana, through the Louisiana highway commission, for the construction of a combined railway and highway bridge across the Mississippi River 2.7 miles above Baton Rouge was among the allocations of funds made by the Public Works Administration during the past week. Plans for the construction of such a bridge have been under way for some time and it is expected that construction can start within two months after the completion of the agreement between the state and the PWA for the loan. The loan is to be sceured by general obligation bonds.

The design for the bridge calls for a structure capable of carrying railroad tracks. In 1930 the Missouri Pacific Railroad applied to the Interstate Commerce Commission for authority to participate in the construction of such a bridge and for approval of an agreement with the Louisiana and Arkansas R.R. for the use of its line on the east bank of the river between Baton Rouge and New Orleans. This application was dismissed last October upon the application of the railroad because a falling off in income made it impossible for it to bear part of the cost of the bridge.

Loan applications sought

Secretary Ickes has instructed the PWA organizations throughout the country to continue to secure qualified applications for loans for non-federal work regardless of the approaching exhaustion of the public works fund. This has been done in order to permit him to report fully upon the desirability of enlarging the PWA program on the basis of money still needed for worth-while projects.

Irrigation work

An allotment of $4,853,000 has been made to Willacy County Water Control and Improvement District No. 1 in the state of Texas to complete the irrigation system in Willacy and Hidalgo counties. A sum of $1,000,000 has been allotted to air conditioning for public buildings in Washington, D. C. The buildings in which air conditioning plants will be installed have yet to be selected.

Railroad loans

Loans totalling nearly $42,000,000 to railroad companies for equipment and construction were approved by the PWA last week. Most of the money is for new locomotives, freight cars and passenger cars, but $2,400,000 of the loan to the Boston & Maine Railroad is to be used on maintenance of way and structures.

An allotment of $28,500 has been made to the Office of Indian Affairs for a new bridge between the Pawnee Indian Agency and the city of Pawnee, Okla., and $22,000 has been given to the same department to

improve the water system of the Cheyenne and Arapahoe Agency in Oklahoma.

Housing loans

An allotment of $84,000 to a limited-dividend corporation in Altavista, Va., for the construction of 50 small houses, has been announced by the PWA. The name of the corporation is not given. The corporation proposes to put up a cash equity of $16,000 to make a total of $100,000. The houses are for mill hands employed in the town who cannot find adequate quarters there.

Non-federal work

Loans and grants totalling nearly $50,000,000 were announced as approved by the Public Works Administration during the past week. The details are given in the accompanying table. Included therein is the loan of $23,160,000 to the city of New York for its Independent subway system, announced in our issue of last week.

Groundwork Being Laid For New York Housing

Events are being so shaped in New York City that when the new administration takes office on Jan. 1, an effective basis will exist for initiating a comprehensive program of slum clearance and low-cost housing. For several days a staff of engineers and architects have been assisting a slum clearance committee, headed by R. H. Shreve, to complete a report on New York conditions and requirements to be presented to the PWA authorities at Washington. The study is being financed by CWA funds.

Mayor-elect LaGuardia has stated several times that slum eradication will be one of the prime objectives of his administration. Last week he appointed Langdon W. Post as tenement house commissioner, and Mr. Post immediately announced his plans to abolish the tenement house department and reorganize it into a housing commission which will have city-wide slum clearance and modern low-cost housing as its principal objective. Under the present housing laws the city has the right to acquire land and lease it to limited-dividend corporations. Mr. Post plans to go further and make housing completely municipal. This will require legislative action, and a bill is to be laid before the legislature next month providing for the establishment of municipal housing authorities, eligible for financing assistance from the Federal Emergency Housing Corporation. All the numerous plans and suggestions which have been advanced for improving housing conditions will be examined and fused into a single program, according to Mr. Post.

Floodway Work—A Correction

In the head of a news item concerning flood control work being carried on under the direction of the International Boundary Commission, published last week, it was stated that floodway work to be carried on in the adjoining towns of Nogales, Sonora, and Nogales, Arizona, was on the Rio Grande. This statement was in error. These towns are located on the border between Arizona and Mexico west of the point where the Rio Grande forms the international boundary.

DETAILS OF PWA LOANS AND GRANTS FOR NON-FEDERAL WORK

Locality	Loan and Grant or Grant	Type	Man-Months Work Provided	Amount
Eau Claire, Wis. (amended)	L. & G.	Water Supply	1,200	$15,000
Huntingburg, Ind. (amended)	G.	Waterworks	300	23,000
Carlisle, Penn. (amended)	G.	Sewage	720	51,000
Milford, Conn.	L. & G.	Sewage	3,600	945,000
Gardner, Kan.	L. & G.	Waterworks	129	37,000
Savanna, Ill.	L. & G.	Waterworks	300	72,000
Itasca County, Minn.	G.	Buildings	240	23,200
Des Moines, Iowa	G.	General Improvements	70	3,000
Glen Rose, Texas	L. & G.	Waterworks & Sewage	400	63,000
Mascoutah, Ill.	L. & G.	Waterworks	400	100,000
Pittsburg, Texas	L. & G.	Waterworks	480	108,000
Warren, Texas	L. & G.	School Building	130	40,800
Broadalbin, N. Y.	L. & G.	School Building	450	175,000
Barnesville, Ohio	L. & G.	Waterworks	600	114,000
University of Texas	L. & G.	Buildings	3,250	1,633,000
Beaumont, Texas	G.	Reservoir	500	26,000
Beaumont, Texas	L. & G.	Waterworks	1,800	216,000
Chadwick, Ill.	L. & G.	Storage Tank	24	6,000
Clayton, Miss.	G.	Court House	3,060	318,000
San Antonio, Texas	L. & G.	Sewers	1,200	115,000
State of Massachusetts	L. & G.	Highways	85	23,000
Granbury, Texas	L. & G.	Waterworks	25	6,000
New York, N. Y.	L. & G.	Subway	147,400	23,160,000
Winthrop, Mass.	G.	Sewage	600	22,000
Lincoln, Neb.	G.	Streets	274	14,000
Blackwell, Okla.	G.	Smoke Stack	2	300
Mansfield, Ohio	G.	Sewer	28	1,000
Whittemore, Iowa	G.	Water Tank	18	2,000
Mansfield, Ohio	G.	Sewer	60	4,000
Highland County, Ohio	G.	Garage	140	10,000
Sioux City, Iowa	G.	Bridge	120	9,000
Des Moines, Iowa	G.	Streets	170	10,000
Ogden, Iowa	G.	Water Tank	12	2,000
Tooele, Utah (amended)	L. & G.	Waterworks	400	15,000
Kamas, Utah (amended)	L. & G.	Waterworks	60	3,500
Uniontown, Ala.	L. & G.	Waterworks	20	2,000
Butte, Mon.	L. & G.	Dormitory	847	320,000
Fort Pierce, Fla. (private)	L.	Warehouse	1,250	380,000
Rock County, Wis.	L. & G.	Buildings	1,392	248,000
Wayne, W. Va.	L. & G.	Waterworks	90	25,000
Salisbury, Md.	L. & G.	Waterworks	2,300	139,000
Columbus, Ohio	L. & G.	City Hall Addition	1,375	449,000
Ortonville, Minn.	L. & G.	Sewage	120	32,000
Glynn County, Ga.	L. & G.	Airport	600	105,000
Glynn County, Ga.	L. & G.	Dry Dock	105	37,000
Cumberland, Md.	L. & G.	Sewers	1,200	300,000
Cushing, Okla.	L. & G.	Municipal Power Plant	700	350,000
Canton, Ohio	L. & G.	Sewer	180	40,000
Lake City, Minn.	L. & G.	Sewage Plant & Warehouse	490	80,000
Madison, Ind.	L. & G.	Waterworks	80	60,000
Brookline, Mass.	L. & G.	Sewers	80	16,000
Conway Corp., Conway, Ark. (private)	L.	Power Plant	32	45,000
Brookline, Mass.	L. & G.	Streets	150	33,000
Williamsburg, Va.	L. & G.	Sewage	1,280	224,000
Quincy, Mass.	L. & G.	Sewers	1,200	159,000
Marshall, Texas	L. & G.	Sewage	890	143,000
French Lick, Ind.	L. & G.	Sewer	75	11,000
New Bedford, Mass.	L. & G.	Water Main	1,275	500,000
Peoria Heights, Ill.	L. & G.	Waterworks	240	84,000
Quincy, Mass.	L. & G.	Sewer	2,400	339,000
Santa Monica, Calif.	G.	Buildings	50	3,000
Holland, N. Y.	L. & G.	Waterworks	400	81,000
State of Louisiana	L. & G.	Baton Rouge Bridge	31,900	7,000,000
Whitney, Texas	L. & G.	Water Ext.	45	8,000
Bemidji, Minn.	L. & G.	Sewage	780	99,000
New Bedford, Mass.	L. & G.	School	1,440	500,000
Azusa, Calif.	L. & G.	Sewer	1,000	180,000
Tehachapi, Calif.	L. & G.	School	120	43,000
Cameron, S. C.	L. & G.	Waterworks	105	33,000
Fortuna, Miss.	G.	School	25	1,800
Peoria, Ill.	L. & G.	Sewage	45	7,000
Redan, Ga.	L. & G.	School	68	17,000
State of Massachusetts	L. & G.	Highways	96	35,000
State of Massachusetts	L. & G.	Highways	52	13,000
Greenwood, S. C.	L. & G.	Sewer	400	47,000
State of Massachusetts	L. & G.	Hospital	459	164,000
Sumter, S. C.	L. & G.	Waterworks	320	66,000
Cincinnati, Ohio	G.	Sewer	3,600	117,000
New York, N. Y.	L. & G.	Hospital	7,200	4,000,000
Hoke County, N. C.	L. & G.	School	280	56,000
Hope, Ind.	L. & G.	Waterworks	180	56,000
Kingston, Penn.	G.	Sewers	60	4,000
Danville, Ky.	L. & G.	Waterworks	325	100,000
University of Minnesota	G.	Building	1,000	86,000
State of Massachusetts	L. & G.	Highway	850	229,000
Gibsonville, N. C.	L. & G.	Water	120	22,000
Los Angeles, Calif	G.	Fire Station	21	2,000
Watonwan County, Minn.	G.	Highway Improvement	200	10,000
Los Angeles County, Calif.	G.	Roads	7,000	406,000
Yadkin County, N. C.	L. & G.	School	600	199,000
Shasta County, Calif.	G.	Building	330	25,000
Oakland, Calif.	G.	Streets	63	4,000
Wallingford, Conn.	G.	Sewage	210	10,000
Rollingstone, Minn.	G.	Slab Roof	4	1,000
Madisonville, Ky.	G.	Fire House	76	6,000
State of Massachusetts	L. & G.	Sewer	200	42,000
University System of Georgia	L. & G.	Buildings	8,540	3,570,000
State of Indiana	G.	Bridges	200	11,000
Brantley County, Ga.	G.	Jail	60	5,000
Brock, Okla.	G.	School	8	1,000
State of Indiana	G.	Bridge	360	24,000
East Greenville, Pa.	G.	Storage Tank	30	4,000
State of Massachusetts	L. & G.	Highways	84	25,000
New Bedford, Mass.	L. & G.	Streets	2,160	428,000
State of Massachusetts	L. & G.	Streets	325	120,000
		Total	269,010	$49,337,600

Included in this table is the loan and grant of $23,160,000 to the city of New York. This loan was recorded in our issue last week.

S. B. Slack, Engineer Examiner for PWA, Dismissed by Ickes

Searcy B. Slack, engineer examiner for the Division of Inspection of the Public Works Administration at Atlanta and former bridge engineer for the state highway department, was dismissed by Administrator Ickes on Dec. 18. In a telegram to Mr. Slack Mr. Ickes said: "Following an investigation you are hereby separated with prejudice as engineer examiner and your appointment as state engineer inspector is cancelled forhtwith."

The official statement concerning Mr. Slack's dismissal says that this action resulted from establishment of the fact that engineer Slack told Georgia State officials that he could secure a $2,000,000 allotment of public works funds to be used by the state highway department for the construction of bridges if paid a 5 per cent commission for services in drawing the plans and specifications for the bridges upon resignation.

Mr. Slack in reply to a request from this journal for a statement as to his dismissal states: "Due to pressure on the state highway department in placing its delayed program under way little attention has been given to possibility of securing public works funds. I proposed to the Governor that if agreeable to state authority and public work authority I would immediately resign from my position with the state PWA engineers and undertake work for the state handling separation of plans and supervision of such bridge work as might be included on the usual 5 per cent fee basis, and road work on the nominal cost of handling the application. I made no claims of having any influence with the PWA and had no discussion in regard to paying me any sum or commission for securing loans. Engineering fees were to be paid only on work actually planned and supervised. Implication that I tried to get 5 per cent commission for securing federal loan for bridges is false. No statement of charges or hearing has been given. I dictated a hasty statement not knowing for what it was to be used. The state advisory board and state engineer PWA have been entirely ignored, being given no opportunity to investigate or report. Consider the action hasty, drastic, and unfair."

Robert Ridgway Retires From New York Subway Work

Robert Ridgway, consulting engineer to the Board of Transportation of the city of New York, retired from active service on Dec. 16, after nearly 50 years of continuous service with the city which began as an instrumentman on the aqueduct for the Croton system in 1884.

In November of last year Mr. Ridgway retired as chief engineer of the Board of Transportation but on account of the death of John R. Slattery, deputy chief engineer, shortly before the time set for his retirement, Mr. Ridgway has continued active connection with the engineering department of the city's subway system.

Jesse B. Snow, division engineer of the Board of Transportation, has been named to succeed Mr. Ridgway. Until his appointment is confirmed his title will be acting chief engineer.

Mr. Ridgway expects to take up private practice as a consulting engineer.

Indianapolis Track Elevation in Difficulties Over Financing

The track elevation program of the Indianapolis Belt Railroad can only be continued if the city receives federal aid on its share of the work, according to a statement made by city officials to the Indiana advisory board of the Public Works Administration. The total cost of the work is estimated at $6,000,000, of which the city would be required to pay $1,428,000, assuming that a 30 per cent grant or about $1,600,000 could be obtained from the PWA. The Belt Railroad would pay $2,100,000 and the county $672,000.

C. F. Messinger, President of Chain Belt Co., Dies

Clifford F. Messinger, president of the Chain Belt Co., Milwaukee, Wis., and well known figure in the construction equipment field, died suddenly of heart failure at his home in Milwaukee on Dec. 12. Mr. Messinger was born in New Haven, Conn. in 1889 and graduated from Sheffield Scientific School, Yale University, in 1911. The same year he went to Milwaukee to enter the service of the Chain Belt Co. as a college apprentice. In 1913 Mr. Messinger was appointed advertising manager and then successively became sales manager, general manager, vice president and in December, 1930, president of the company. In addition to his work with the Chain Belt Co., Mr. Messinger took an active part in related operations in the equipment manufacturing field.

Difficulties Over Appointments Delay Twin City Sanitary Work

Controversy over the appointment of trustees for the newly organized Minneapolis-St. Paul Sanitary District has delayed the organization work of the district and has resulted in the sending of the chairman, chief engineer and attorney into Washington to confer with the Public Works Administration in order to determine what steps can be taken to facilitate financing the proposed work of the district with PWA funds. The controversy centered around the appointment of two trustees to represent the city of St. Paul. A resolution adopted by the city council appointing two trustees was vetoed by the mayor, and after the state attorney-general had ruled that the mayor's veto was valid under the city's charter, the governor appointed two men acceptable to the mayor. Subsequently the state supreme court ruled that the appointments made by the city council were valid, that the provisions of the state act setting up the sanitary district are not controlled by the city's charter.

NEW YORK BOARD OF WATER SUPPLY ENGINEERS HONOR THADDEUS MERRIMAN

Thaddeus Merriman, who retired as chief engineer of the Board of Water Supply of New York City on Nov. 30, was the guest of honor at a dinner held in New York on Dec. 14. The dinner was given by Mr. Merriman's associates on the board, by former engineers of the board and engineers of the city who have been associated with him in consulting and professional work. It took the place of the "chief's dinner," an annual event in the engineering department of the Board of Water Supply since the early days of its organization. An account of Mr. Merriman's service with the board was published in our Nov. 30 issue.

Rehearing Begun on Canal To Serve Youngstown District

Reconsideration of the proposed canalization of the Beaver and Mahoning rivers in Pennsylvania and Ohio to serve the Youngstown steel district was begun in Washington on Dec. 12 before the Board of Engineers for Rivers and Harbors of the War Department.

Some time ago the army engineers reported against the proposed work on the ground that it was not economically justifiable and that there was not adequate water supply for the canal system.

Water Supply Program of Denver To Be Put to Vote on Jan. 23

Extension of the water supply for the city of Denver is the largest among eight items to be put to vote at a special election to be held on Jan. 23. Recently the Public Works Administration authorized the allocation of funds to be used by the city of Denver to bring water to the city from the west slope of the mountain through the pioneer bore of the Moffat tunnel.

Other projects included are $2,000,000 for a sewage disposal plant, $733,000 for protective work along the Platte River, and $1,000,000 for flood control work on Cherry Creek, the stream on which serious damage occurred in Denver following a cloudburst on the headwaters earlier in the year.

New York Requests Funds For Incinerator Construction

New York City has applied to the Public Works Administration for a loan and grant totalling $5,800,000 to complete its program of constructing refuse incinerators.

The largest element in the program is to be the erection of an incinerator on Rikers Island. Detailed plans for this plant have not yet been completed but its capacity is to be in the neighborhood of 2,000 tons per day. Not only will the plant burn the refuse to be carried to it but it will be designed to operate also on the vast amount of refuse that has accumulated on Rikers Island through many years of dumping. A steam boiler will be provided at the plant and electric power is to be generated.

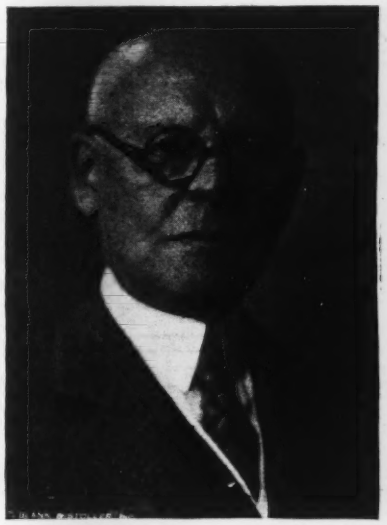
The program also includes the construction of three new incinerators, one in Manhattan to replace an existing plant which is to be abandoned, one in the Bronx, and one in Queens to replace the existing plant at Flushing. Two other existing incinerators in the borough of Queens are to be enlarged and mechanized.

Two contracts were awarded during the week ending Dec. 16 for the mechanization of two existing incinerator plants in Manhattan.

Action was recently taken by the United States Supreme Court allowing the city until July 1 to discontinue dumping garbage and rubbish at sea. The action was based upon the complaint of New Jersey communities that the sea-dumped refuse was being deposited upon northern New Jersey beaches. Although the construction program cannot be completed for the date set, dumping at sea will be discontinued, the material now being disposed of in that manner being provided for largely through increased efficiencies in present methods of disposal.

A. A. Stevenson, Long Active in A.S.T.M. Work, Dies

Archibald A. Stevenson, until his retirement in 1929 vice-president of the Standard Steel Works Co., died at his home in Ardmore, Pa., on Dec. 15, age 72 years. Mr. Stevenson was born in Allegheny City, Pa., and studied engineering for two years at the University of Illinois. After several years with the Southwark Foundry & Machine Co., Philadelphia, he went to the Cambria Steel Works, at Johnstown, soon becoming foreman of the axle plant. From



Archibald A. Stevenson

that company he went to the Standard Steel Works Co., Burnham, Pa., as traveling engineer, and advanced successively to the positions of manager of the wheel department, assistant superintendent, superintendent, and, in 1908, vice-president. While at Burnham he was one of the pioneers in introducing the microscope into practical steel investigation.

Mr. Stevenson had been active in the American Society for Testing Materials since its organization, having been a member of the International Association for Testing Materials at the time the American group severed its connection with that organization to form a new society on a broader basis. Failure of the International Association to interest itself in standardization was one of the reasons for the formation of the new society, and Mr. Stevenson led in developing that feature of the society's work. Dr. Charles B. Dudley and Prof. Edgar Marburg, together with Mr. Stevenson, were the three men who perhaps did more than any others to shape and guide the new organization during its early years. He served for many years on Committee A-1, the iron and steel committee, serving as chairman of some of its subcommittees for many years.

He was elected a member of the executive committee in 1911, a vice-president in 1914 and president in 1916. In 1927 he was elected an honorary member of the society. He also served as president of the Association of American Steel Manufacturers, and during the war was chairman of the Gun-Howitzer Production Club, an organization formed by producers of large gun forgings to speed up production.

Mr. Stevenson's interest in standardization led to his becoming in 1918 one of the organizers of the American Engineering Standards Committee (the present American Standards Association), and for two years he served as the chairman. He also was chairman of the planning committee of the Division of Simplified Practice, U. S. Bureau of Standards.

SOCIETY CALENDAR

AMERICAN CONCRETE INSTITUTE, Toronto, Ontario, Canada, Feb. 20-22, 1934.

AMERICAN RAILWAY ENGINEERING ASSOCIATION, Chicago, Ill., March 13-14, 1934.

AMERICAN ROAD BUILDERS ASSOCIATION, annual convention, Chicago, Jan. 22-26, 1934.

AMERICAN SOCIETY OF CIVIL ENGINEERS, annual meeting, New York, Jan. 17-20, 1934.

AMERICAN SOCIETY FOR TESTING MATERIALS, Atlantic City, N. J., June 25-29, 1934.

AMERICAN TOLL BRIDGE ASSOCIATION will hold its annual convention at Cincinnati, Ohio, Jan. 26-27

AMERICAN WOOD PRESERVERS ASSOCIATION, Houston, Texas, Jan. 23-25, 1934.

CANADIAN CONSTRUCTION ASSOCIATION, Toronto, Ont., Jan. 22-26, 1934.

ENGINEERING INSTITUTE OF CANADA, 48th annual general meeting, Montreal, Que., Feb. 8-9, 1934.

Purdue Road School will hold its 20th annual session at Purdue, Ind., Jan. 22-26, 1934.

LOS ANGELES CITY AND COUNTY ENGINEERS ASSOCIATION has elected Clarence J. Schultz, street design engineer for the city of Los Angeles, as president to succeed Howard I. Stites, of Burbank. Arthur E. DeMott has been elected vice-president, and Frank Pore secretary-treasurer.

LOS ANGELES SECTION, American Society of Civil Engineers, at its annual meeting held Dec. 13, elected Merrill Butler, bridge design engineer for the city of Los Angeles, president, to succeed Ormond Stone. H. L. Doolittle and Kenneth Volk were elected vice-presidents, John Albers, treasurer, and Andrew Gram, secretary.

INDIANA SECTION, American Water Works Association, meeting Dec. 6 and 7 at Fort Wayne, approved efforts to restore confidence and employment through PWA and CWA. City officials and those in charge of water supplies and sewerage systems were urged to carry out needed improvements now. The meeting followed dedication of the Fort Wayne new 25-m.g.d. water purification and softening plant treating the Saint Joseph River water to replace a hard well water high in iron. A symposium on collections and meters included results of a questionnaire as to shut-off practice. In practically all cases rates have been modified, partial payments are accepted. Per cent of delinquencies as reported varies from 2.5 to 50 per cent. Relief agencies are making some payments. In half the cases customers may work out their bills and in half landlords are held responsible for bills. Office work due to delinquencies in Indianapolis has increased 50 per cent. In LaPorte collections normal in 1932 now are 20 per cent delinquent. Charles Brossman in a paper on "Water Works Construction with Relief Labor" stated that the cost per capita for poor relief is double that for repaying the investment. Of 17 projects the cost per consumer is only 76c. per year, varying from 21c. to $2.35, but the indebtedness incurred will be paid without raising rates. Work under CWA in Indiana involves 36 water and 86 sewage projects, said L. A. Geupel, chief engineer, Indiana State Board of Health. Of 27 PWA approved projects six are for water and four for sewage works, involving more than $3,000,000. Officers elected for the ensuing year include the following: President, W. C. Mabee; vice-president, C. C. Foutz; secretary-treasurer, C. K. Calvert, Indianapolis.

Personal

F. W. YOUNG, formerly with Filtration Engineers, Inc., more recently with the Pulp Filter Co., has joined the sales organization of Oliver United Filters, Inc., New York.

C. CLYDE HARRIS, for the past three years county supervisor of maintenance at Canfield, Ohio, for the state highway department, has resigned and EMERY STAHLSMITH has been appointed to succeed him.

C. H. RICE, of Dover, N. H., formerly employed in the engineering department of the Rock Island Lines, has been appointed project superintendent for the U. S. Forest Service with headquarters at Peru, Vt.

F. R. MOLTHER has been appointed architect for the Quartermaster Corps, Panama Canal Department, in charge of the quarters and technical buildings to be constructed at Albrook Field, Fort Clayton, and France Field in the Canal Zone.

RUSSELL G. HACKETT has been appointed regional engineer for the Civil Works Administration in the region comprising California, Nevada, Utah, Arizona, and New Mexico. He is a civil engineering graduate of Stanford University with 20 years' design and construction experience in the Pacific States and South America.

JOHN CRAWFORD, formerly construction superintendent for W. H. Gahagan, Inc., Brooklyn, is now with the U. S. Bureau of Public Roads on highway construction work in Oklahoma with headquarters at Oklahoma City.

ROBERT L. OATES, formerly a subcontractor on the Wachusett-Coldbrook tunnel of the Boston water supply system, is now with the Arundel Corp. on the construction of the new Hoffman St. tunnel through the city of Baltimore for the Pennsylvania Railroad.

R. C. CHANEY, former county planning engineer of Cuyahoga County, Ohio, Cleveland, has been appointed assistant state engineer inspector, Ohio, Federal Emergency Administration of Public Works. JOHN B. DE HAMEL is state engineer inspector.

GEORGE K. LEONARD of Lincoln, Neb., for the past twenty years associated with Woods Bros. Construction Co. and with the Nebraska state highway department, has been appointed assistant to the engineer in charge of construction on the Joe Wheeler Dam on the Tennessee River for the Tennessee Valley Authority.

Obituary

JAMES P. BROWNELL, former engineer for the village of Carthage, N. Y., died there on Dec. 17, age 65 years. Mr. Brownell was a graduate of Cornell University in the class of 1891.

GEORGE W. CURRIER, for fifteen years an engineer of the bridge department of the city of Boston prior to his retirement about four years ago at the age of 70, died recently at his home in Wollaston, Mass.

C. D. SMITH, former railroad contractor, died at Memphis, Dec. 13, age 69 years. Mr. Smith was connected with the construction of the Santa Fe line across the Mojave desert and with much of the railway construction work in Mississippi. He also was engaged on subway work in New York.

JACK V. LUND, a member of the firm of Charles E. Lund Associates, engineers, St. Petersburg and Tampa, Fla., was killed in an automobile accident at Mariana, Fla., on Dec. 13. Mr. Lund, before entering into association with his father in engineering practice, was a member of the staff of Parsons, Klapp, Brinckerhoff & Douglas, consulting engineers, New York.

CONSTRUCTION STATISTICS OF THE WEEK

A SMALL gain in public and a substantial gain in private construction contracts raised the total this week to $33,628,000, an increase of 14 per cent over the previous week and 63 per cent over the year's weekly average to date. On private contracts this is the third heaviest week this year, $13,003,000, exceeded only in the last week of September and the first week of June. Large individual contracts contributing to this record include the New York Central Railroad grade separation award in Syracuse, $4,021,097, Irvington Housing Corporation apartments, Irvington, New Jersey, $2,678,850, and the Mathieson Chemical Co. plant, Lake Charles, La., $5,000,000.

In the public awards highways maintained their high rate of awards, $10,100,000 compared with $10,500,000 and $10,000,000 respectively the two preceding weeks. Federal work at $5,600,000 dropped slightly below the preceding week. Large individual projects in the public awards include highway awards of $1,157,000 in one block in Kansas, $1,120,000 in New York, $1,047,000 in Georgia, digester tanks Cleveland sewage treatment plant, $1,091,000, Bonnet Carre Spillway bridge, Louisiana, $1,084,000, Lock No. 5, at Winona, Minn., $1,405,000 and dredging at Calumet, Ind., $1,189,000.

New capital topped its increase of last week at a total of $60,548,000 of which $6,352,000 was for private construction and $54,196,000 for public. Of this total $59,147,000 was PWA financing. This included the $26,160,000 allotment for completion of the New York subway work.

CONTRACTS
(Thousands of Dollars)

	Weekly Average Dec. 1932	Prev. 4 Weeks	Week Dec. 21, 1933
Federal Government	$6,095	$7,747	$5,572
State and municipal	10,024	14,563	15,053
Total public	$16,119	$22,310	$20,625
Total private	4,553	6,194	13,003
Weeks total	$20,672	$28,504	$33,628
Cumulative to date:			
1932	$1,198,637	1933	$1,052,341

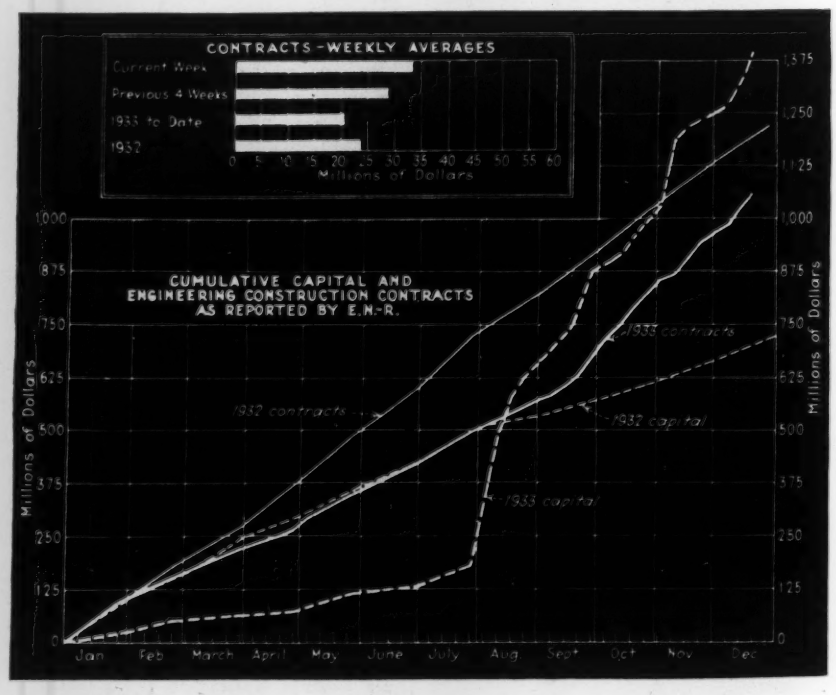
NEW PRODUCTIVE CAPITAL
(Thousands of Dollars)

	Week Dec. 21, 1933	Cumulative 1933
State and municipal	$ 633	$275,315
PWA allotments, public	53,563	874,095
Corporate issues	768	51,248
PWA allotments, private	5,584	198,478
Total new capital	$60,548	$1,399,136
Cumulative, 1932		$705,750

Note: These figures include private bonds and stock sold for productive purposes; state and municipal bonds for construction; R.F.C. advances for self-liquidating loans; PWA loans and grants to state and municipalities, including the special highway funds; and PWA private loans.

INDEX NUMBERS

E.N.-R.-Cost		E.N.-R.-Volume	
December, 1933	**192.14**	**November, 1933**	**133**
November, 1933	190.14	October, 1933	162
December, 1932	158.46	November, 1932	137
1932 (Average)	156.97	1932 (Average)	127
1931 (Average)	181.35	1931 (Average)	220
1930 (Average)	202.35	1930 (Average)	260
1913 (Average)			100


CONTRACTS - WEEKLY AVERAGES
Current Week
Previous 4 Weeks
1933 to Date
1932
0 5 10 15 20 25 30 35 40 45 50 55 60
Millions of Dollars
CUMULATIVE CAPITAL AND ENGINEERING CONSTRUCTION CONTRACTS AS REPORTED BY E.N.-R.
1933 contracts
1932 contracts
1932 capital
1933 capital
Millions of Dollars
0 125 250 375 500 625 750 875 1000 1125 1250 1375
Jan Feb March April May June July Aug Sept Oct Nov Dec